DASA-1777

AD 638842

Best Available Copy

BIOLOGICAL EFFECTS
OF BLAST AND SHOCK

Donald R. Richmond and Clayton S. White

DDC

Lovelace Foundation for Medical Education and Research

Albuquerque, New Mexico

April 1966

200407022018

DASA-1777

BIOLOGICAL EFFECTS
OF BLAST AND SHOCK

Donald R. Richmond and Clayton S. White

Technical Progress Report
on
Contract No. DA-49-146-XZ-055

Lovelace Foundation for Medical Education and Research
Albuquerque, New Mexico
April 1966

PREFACE

This manuscript is based on a lecture entitled "Biological Effects of Blast and Shock" presented to the Allied Command — Atlantic Medical Officers' Symposium, Biomedical Nuclear Weapons Effects Briefings, on October 29-30, 1963, at the National Naval Medical Center, Bethesda, Maryland, which was sponsored by the Defense Atomic Support Agency. Although the lecture, for the most part, dealt with the primary blast effects, this paper has been expanded to include the secondary and tertiary blast effects, along with the range-yield-effects relationships for selected biological criteria.

Most of the information contained herein has been the outcome of two investigative efforts; namely, research in the area of biological effects of blast from bombs supported through the Office of the Surgeon, Defense Atomic Support Agency of the Department of Defense under Contract DA-49-146-XZ-055 and a program in selected aspects of weapons effects supported by the Civil Effects Branch of the Division of Biology and Medicine, U. S. Atomic Energy Commission under Contract AT(29-1)-1242.

ABSTRACT

The scope of blast and shock biology was set forth as covering effects resulting from overpressure (primary), flying debris (secondary), and displacement (tertiary). Procedures employed in the laboratory for simulating the blast wave forms as they varied within structures on nuclear tests were described.

For each effect, a selected summary of current information relating the physical parameters to given levels of biological response was presented. From this, the blast and shock hazards estimated for personnel, as a function of range and yield, were illustrated in the form of curves.

The range-yield-effects relationship for the biological criteria was discussed in terms of free-field and other exposure situations. They were compared with similar range-effects data for thermal and nuclear radiation.

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF TABLES

Table of Contents (continued)

LIST OF FIGURES

Table of Contents (continued)

BIOLOGICAL EFFECTS OF BLAST AND SHOCK

Donald R. Richmond and Clayton S. White

INTRODUCTION

Blast and shock are among the immediate effects from a nuclear explosion since they occur within a few minutes after the detonation. Blast and shock can produce injury and death in several ways: first, as a consequence of the shock front and associated pressure pulse striking and engulfing the body; second, by the debris thrown by the blast wave and ground shock hitting the body; and third, by the body itself being hurled by the air blast with subsequent impact with objects in its flight. These categories have been termed primary, secondary, and tertiary blast effects, respectively, and conveniently divide the problem into three areas of study. Other personnel hazards from blast and shock have to do with the inhalation of high concentrations of dust that have been stirred up by the blast and "non-line-of-site" burning which is believed due to the shock-wave filling of structures with hot, dust-laden air.[1,2]

Experiments with animals in the laboratory and on full-scale tests have been under way for the past decade to develop biological criteria for each effect whereby a given physical parameter (dose) can be associated with resultant levels of biological response. The ultimate aim is twofold; viz., first, to estimate what dose levels are relatively safe for personnel, represent the threshold for injuries, and are correlated with a given mortality level; and second, through the use of appropriate procedures, to scale these as a function of weapon yield and range for various burst conditions. Beyond this, considerable effort has been and is directed to further understanding the nature and mechanism of the injuries encountered, which knowledge is fundamental not only to hazards assessment, but to intelligent diagnosis, treatment, and the development of sound, protective principles.

This task is complicated by the fact that one must take into account the "geometry of exposure;" that is, where one is located at the time of exposure. For instance, at a given range, personnel situated in foxholes or bunkers would be exposed to minimal hazards from flying debris compared to what might be the case in the open or inside typical buildings. Consequently, the biological criteria for the various yield and range relationships must be scaled for free-field conditions as well as for other geometries of exposure (geometric scaling).

It is the intent of this report to present some of the more pertinent information gathered to date on primary, secondary, and tertiary blast effects, from which tentative biological criteria have been derived and with which range-yield-effects relationships for personnel have been compiled recently.

PATTERNS OF AIR-BLAST WAVES

Since biological response to overpressure depends a great deal upon the exact shape of the pressure-time pattern which can be altered markedly when it enters a structure, it is appropriate here to present illustrations of pressure-time records taken in some shelters during nuclear tests.

In general, the form that the pulse takes upon entering a structure depends on such things as the area of the opening and its orientation to ground zero, the volume and geometry, and, of course, the characteristics of the incident wave.

In Figure 1 are pressure-time records recorded in and adjacent to an underground group shelter located 1,050 ft from a 29-kt explosion.[1-3] The shelter was partitioned into two separate rooms: the fast-fill room which filled through a 6 x 3-ft door and the slow-fill room where the blast wave entered through a 3 x 3-ft escape hatch. The incident wave was of the precursor type and had a peak pressure of about 90 psi, which occurred after the first 50 msec (in contrast to an ideal wave in which the peak pressure occurs at the leading edge of the wave). The wave form in the fast-fill chamber was characterized by a series of initial shocks with a subsequent climb to a maximum of 65 psi in 80 msec. A similar pattern was recorded in the slow-fill chamber, except the pressure only rose to 22 psi, since it filled through a smaller opening.

Dogs in this shelter which were restrained to prevent tertiary effects were recovered alive, except for one animal located just inside the 3 x 6-ft door, that was blown against the opposite wall and killed by the impact. Most of the animals sustained eardrum rupture, hemorrhagic sinuses, and thermal effects ranging from fur singeing to skin burns.

Figure 2 gives the pressure-time records associated with two underground, basement-exit shelters — both at the 1,350-ft range from a 14-kt detonation on top of a 500-ft tower. The shelter was 3 x 13 ft and 5 ft high. One shelter was closed by four wooden, hatch-type doors over the entryway and the other was left half-open with two wooden hatches over the stairway; however, all doors were blown away by the blast. Again the incident wave was of the nonideal type with a peak pressure of about 17 psi. In the initially closed shelter, the wave form was characterized by a series of pressure oscillations. The peak pressure was less than that in the incident wave. On the other hand, in the half-open shelter, the pressure rose in a "step" manner to about twice that of the incident wave.

GROUP SHELTER
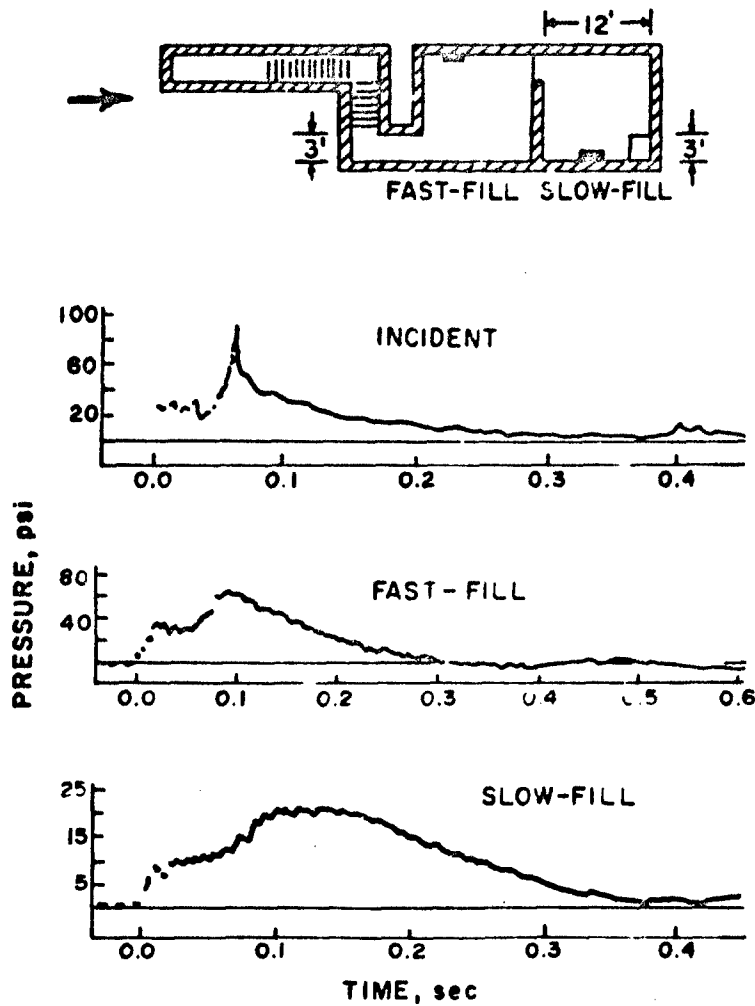
Figure 1. Pressure-time record outside and within the slow-fill and fast-fill rooms of the underground group shelter located 1,050 ft from ground zero. [1-3]

BASEMENT EXIT SHELTER
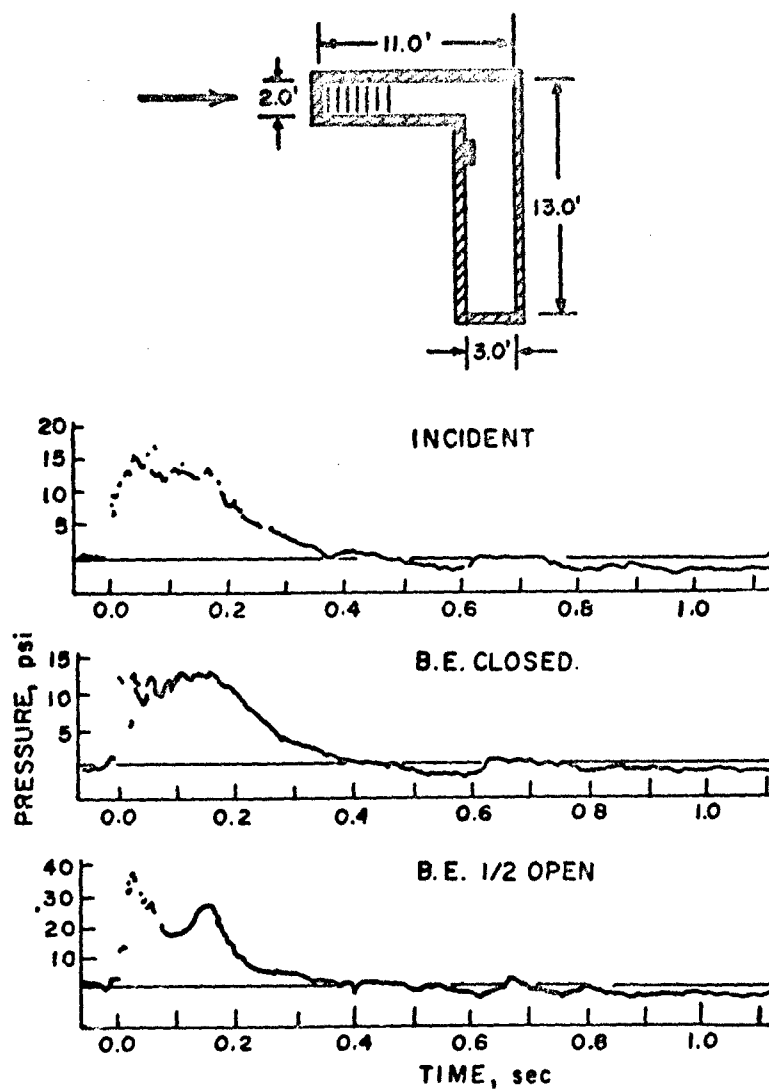
Figure 2.   Pressure-time recorded outside and within underground closed and half-closed basement-exit shelters located 1,350 ft from ground zero. [1-3]

No pathological lesions were noted in two dogs that experienced the oscillating pressures of about 12 psi in the closed shelter. Dogs in the half-open shelter, which experienced near 40 psi rising in a "step" fashion, exhibited ruptured eardrums and sinus hemorrhages.

Figure 3 contains examples of smooth, slow-rising pressure patterns occurring in shelters that were within conventional houses at the 4,700-ft range from a 29-kt explosion. In the bathroom shelter, the pressure peaked in near 0.5 sec. In the lean-to shelter, it rose faster — peaking in about 0.1 sec. There was a 5-psi incident shock wave of the ideal form.

Animals in these shelters were unhurt, even though the houses were completely destroyed.

GENERATION OF AIR-BLAST WAVES IN THE LABORATORY

As with the other weapons effects, there arose the need for simulating blast and shock phenomena in the laboratory. Considerable success has been achieved using shock tubes and high explosives in generating air blast of the desired wave forms. Before turning to the biological effects, it might be well to describe some of the apparatus involved in producing air blasts similar in form to those shown in the previous section that were recorded full-scale.

Figure 4 illustrates a shock tube developed to generate sharp-rising pulses of long duration. The overall length is about 70 ft. It consists of a 17-ft-5-in. compression chamber separated by a rupturable diaphragm from the 53-ft-4-in. expansion chamber. The compression chamber and the distal portion of the expansion chamber is 40.5 in. in diameter. The low pressure side is closed by an end-plate against which animals, ranging in size from mice to goats, are tested. [4]

To operate the shock tube, air is pumped into the compression chamber to a predetermined level and the diaphragm ruptured. The explosively released air sends a shock wave down the expansion chamber. The shock front obeys the same physical laws as one generated by a nuclear burst. It heats and compresses the gas through which it passes and imparts particle velocity to it. Upon striking the end-plate, it reflects and travels upstream, further increasing the pressure and stagnating the flow. The relief vents in the tube serve to bleed off some of this reflected shock front to prevent it from returning to the end-plate. These vents also serve to control the duration of the overpressure. A typical pressure-time pattern recorded by a gauge in the end-plate is shown in Figure 4, and is characterized by an initial, sharp rise associated with the reflected shock front and a duration of approximately 400 msec.

By altering the various components, sharp-rising pulses of 80-, 54-, 30-, 20-, and 15-msec duration were generated and assessed biologically. This was accomplished by shortening the compression and expansion chambers

SHELTERS IN HOUSES

CONCRETE BATHROOM SHELTER

BASEMENT LEAN-TO SHELTER

SIDE VIEW   TOP VIEW

BATHROOM

LEAN-TO

INCIDENT

PRESSURE, psi

TIME, sec
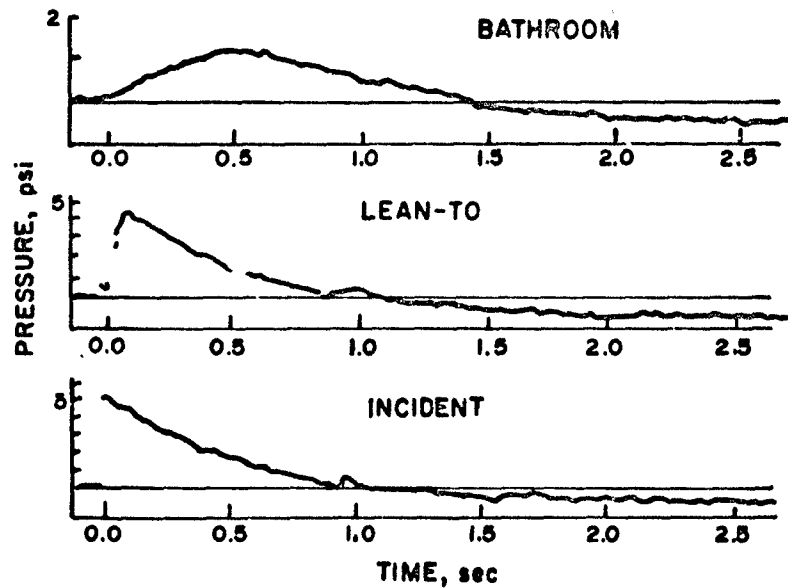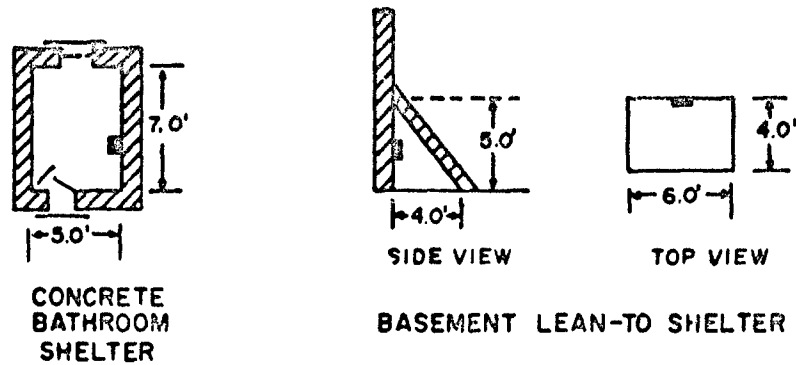
Figure 3.   Pressure-time recorded outside and within a bathroom shelter and a lean-to shelter located inside of houses at the 4,700-ft range from ground zero. [1-3]
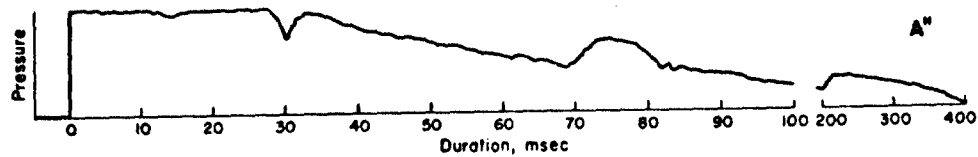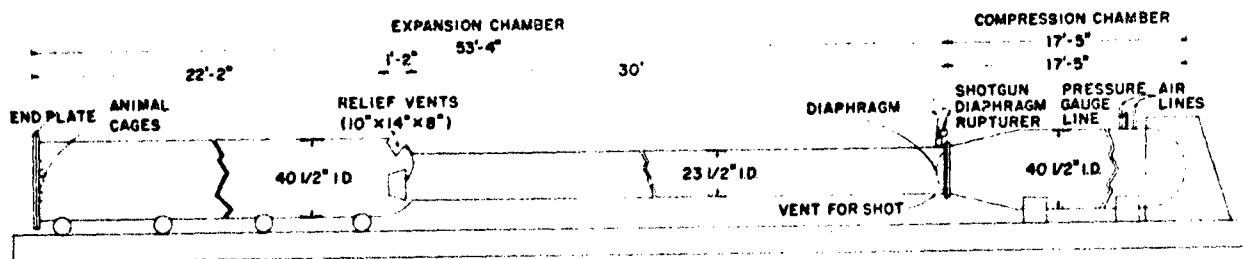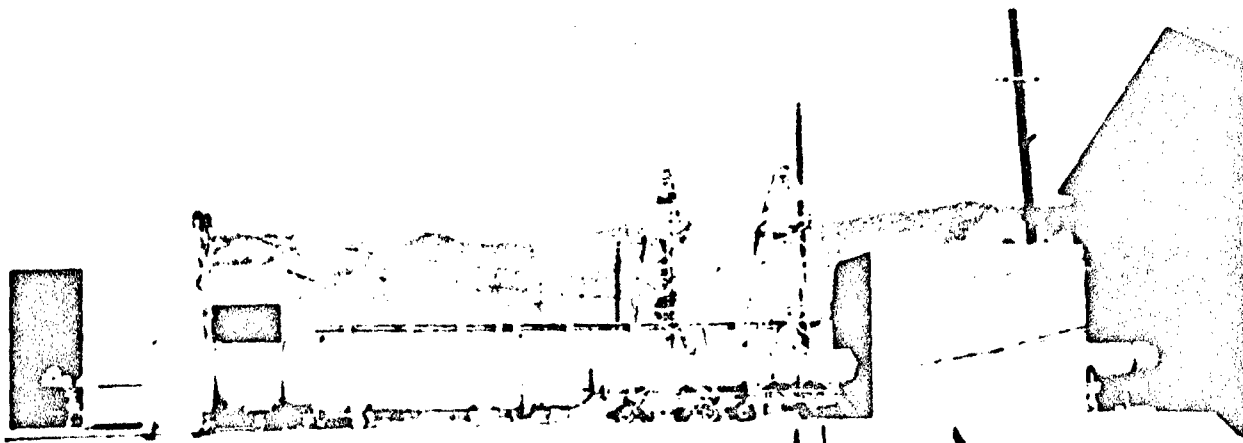
Figure 4. Shock tube that generated sharp-rising overpressures of about 400-msec duration.

and introducing short gaps at appropriate flanges in the tube. To investigate the biological response to yet shorter blast waves, high explosives were employed.

Figure 5 shows a blast site where high-explosive charges were detonated overhead to generate very short-duration, sharp-rising pressures on a concrete pad.[5] It can be seen that animals on the pad were exposed in a manner analogous to those on the end-plate of the shock tube. With high-explosive charges ranging in weight from 1/2 oz to 64 lb, maximal pressures near the P_{50} range were produced of 0.4- to 7-msec duration. Oscillogram recordings from pencil piezoelectric gauges mounted in the concrete of the pad show that the 1-lb charge at 7 ft produced a 1.3-msec-duration blast and the 8-lb charge at 13 ft yielded a 3.1-msec-duration blast. Since the gauges were mounted a fraction of an inch above the surface, the records clearly show the incident and reflected shock fronts. It is significant that the latter were of sufficient magnitude to allow lethality studies in various mammalian species.

Step-Rising Air Blasts

Figure 6 is a diagram of a 23.5-in.-diameter shock tube of uniform, cross-sectional area throughout, along with illustrations of the initial portions of several pressure-time patterns recorded in the tube.[6] Small animals can be subjected to pressures that rise in one or two steps, with the time between steps varied by placing the animal in a foxhole-like mount in the wall of the tube and moving the reflecting plate attached to the end of the tube, after the method of Schardin and Wünsche.[7] The steps correspond to the incident and reflected shock fronts. With the reflecting plate over its thorax, the animal's lung was subjected to the incident and reflected shocks almost simultaneously (see record C-1). When the reflecting plate was at 1, 2, and 3 in. downstream from the thorax, the interval was 0.14, 0.28, and 0.42 msec, respectively, between the incident and reflected shock (records $C-1_1$, $C-1_2$, and $C-1_3$). As will be pointed out later, such small time intervals are important to the response of animals that also receive step-loads when placed at short distances upstream from the end-plate closing the tube.

Related studies were undertaken with guinea pigs in model foxhole chambers at the bottom of the shock tube.[8] Illustrated in Figure 7 is the simple, deep chamber (3 x 8 x 8 in.) and the pressure-time recorded in the tube at different sides of the chamber. Two factors of significance were readily apparent. First, the peak pressure in the deep chamber was higher than that of the incident wave. Second, the leading edge of a pressure wave was step-rising and quite different on the upstream, downstream, and side walls of the chambers. Both factors influence biological response and have a direct bearing on the protection from primary blast effects.

Slow, Smooth-Rising Air Blasts

A diagram of the shock-tube configuration, in which slow, smooth-rising pressures that peaked in about 87 msec were produced, is illustrated in the
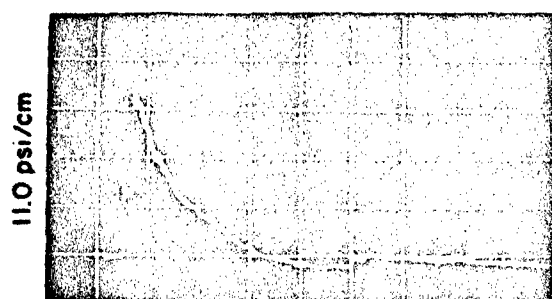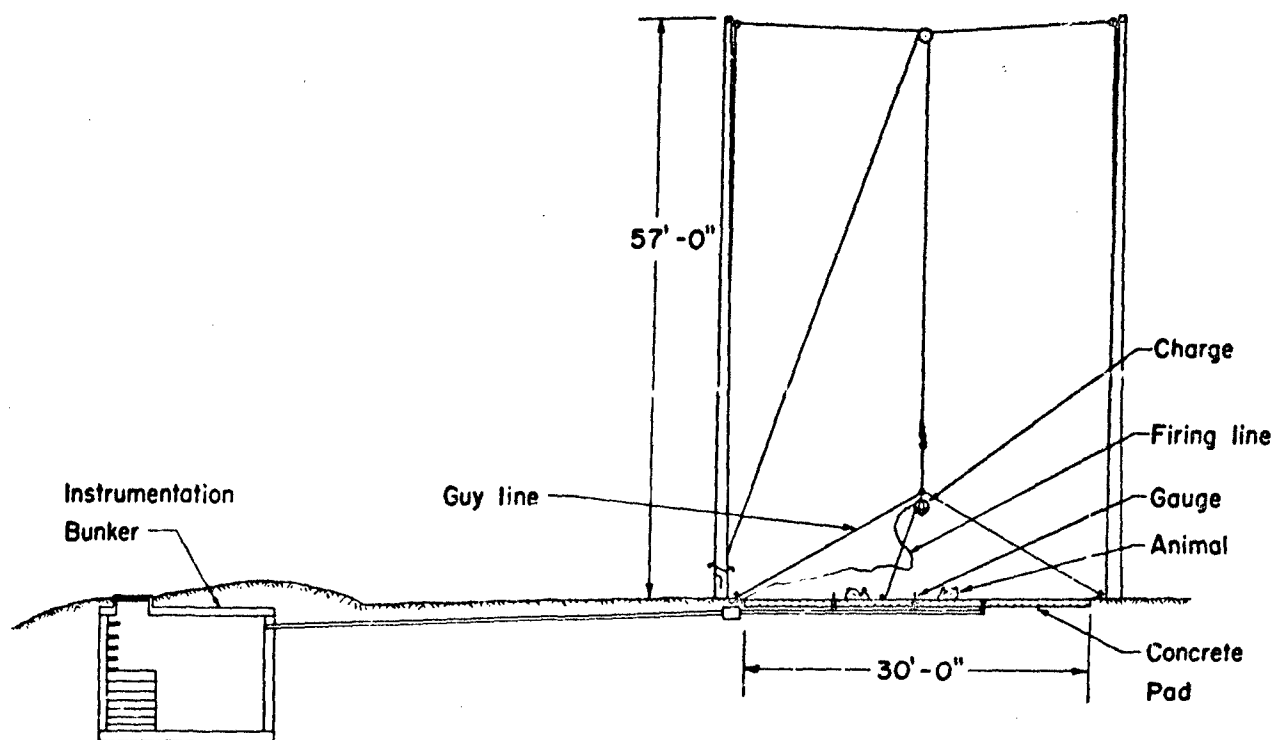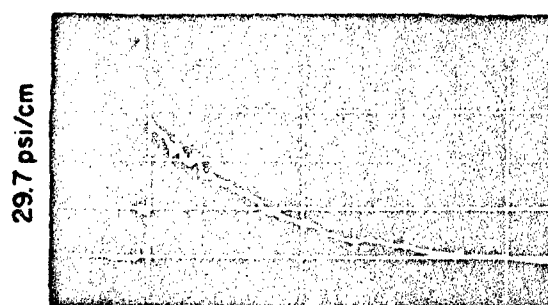
Figure 5. Blast facility where high-explosive charges of various weights were employed to generate sharp-rising air blasts for short durations. [5]
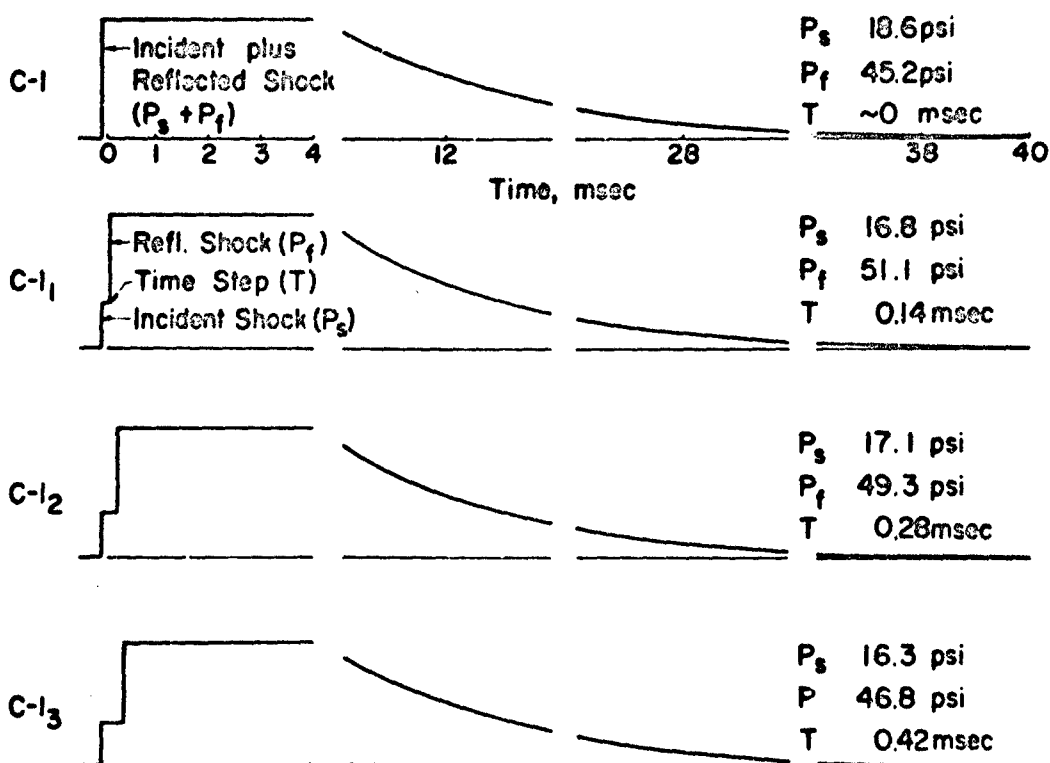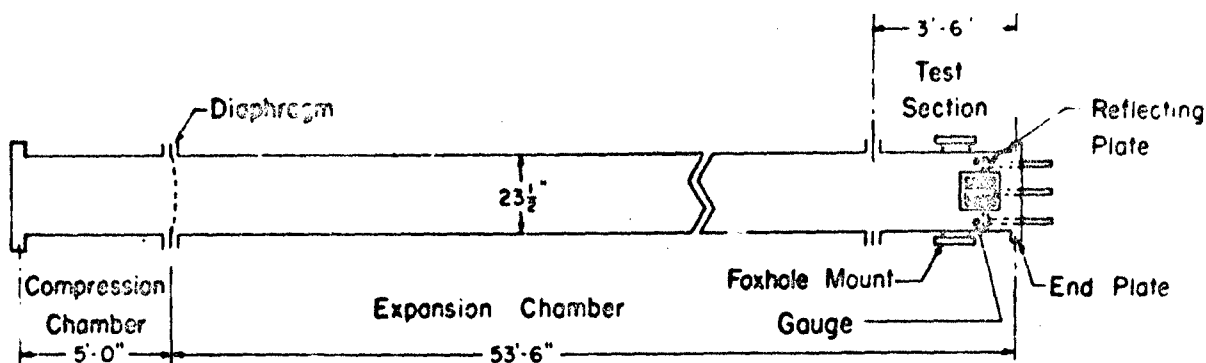
Figure 6. Shock tube fitted at the end with an adjustable re-
flecting plate for generating step-rising over-
pressures. [6]
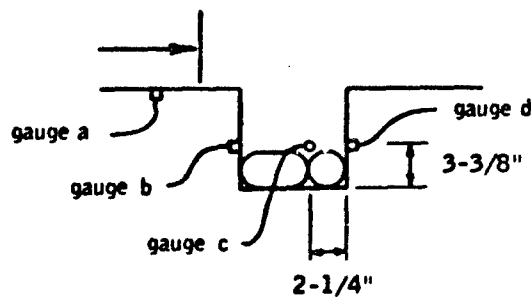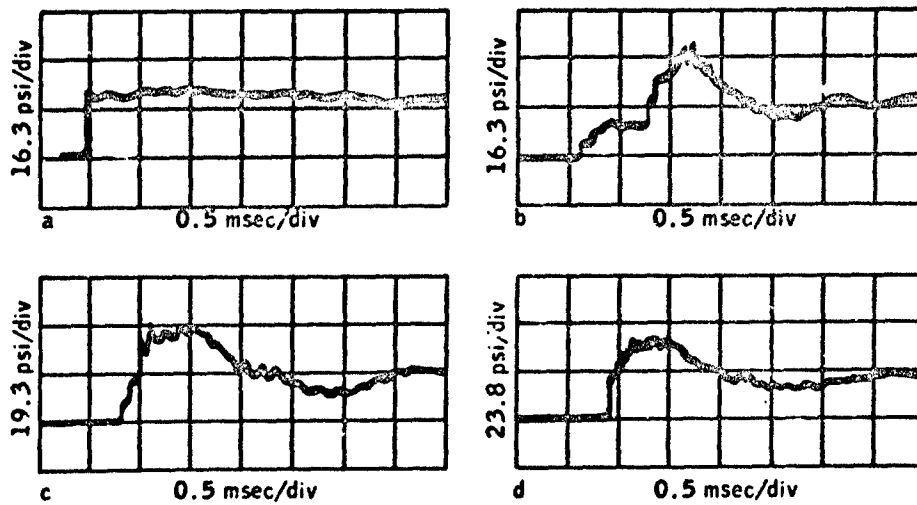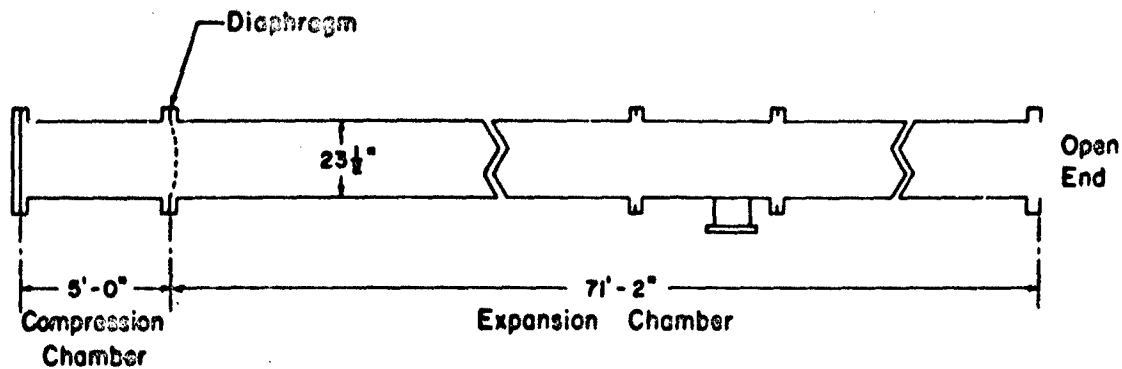
Figure 7.   Pressure-time records associated with the simple,
            deep model foxhole on the shock tube. [8]

upper portion of Figure 8. Similar wave forms that peaked in 30, 60, 90, and 150 msec were generated by varying the volume of the expansion chamber and the area of the opening through which it filled.[9]

Other Air Blasts

The lower portion of Figure 8 presents the shock tube (Arrangement 13) and associated pressure-time recording. The latter is characterized by a series of multiple-shock reflections at the leading edge followed by a "crown" or a more gradual climb to the peak level. This wave form is not unlike that recorded in the group shelter (Figure 1).

PRIMARY BLAST EFFECTS

General

Although a detailed account of the nature of the pathological lesions produced by blast will be given elsewhere, a few points deserve mention here. Experiments in which different portions of an animal's body were shielded clearly showed that it is necessary for the air blast to strike the chest of the body to cause lung injury.[10] Injuries occur as a result of the pressure wave acting directly on the body wall and not from the pressure passing into the lung from the respiratory passageways, as previously supposed.

A definite pattern of injuries occur from primary effects; namely, hemorrhage and disruption of tissues in those regions of the body wherein there exists the greatest variation in tissue density. Especially involved are the air-containing organs of the body: lungs, ears, gas-containing portions of the gastrointestinal tract, and sinuses. The most dangerous lesion associated with very short survival time is air embolism; that is, air bubbles enter the circulatory system from a damaged lung and pass into the heart and brain with lethal consequences. Animals killed by primary blast effects exhibit no external signs of injury except for blood or bloody froth exuding from their noses and mouths — the latter as a consequence either of the lung injury or damage to the paranasal sinuses.

As already mentioned, biological response depends a great deal upon the form or shape of the air-blast wave. For study purposes, they have been grouped into ideal and nonideal wave forms.[2,8] Ideal waves are those that rise in an instantaneous or near-instantaneous manner like those illustrated in Figures 4 and 5. All other possible patterns have been termed nonideal forms: such as step-rising; smooth, slow-rising; oscillating pressures; or combinations of these.

Biological Tolerance to Ideal Wave Forms

In general, biological response to air-blast waves of the ideal type is related to the magnitude (peak pressure) and the duration of the pressure.

Pressure-Time Record
Arrangement 4

Pressure, psi

75
50
25
0

0   50   100   150   200   250   300   350

Time, milliseconds
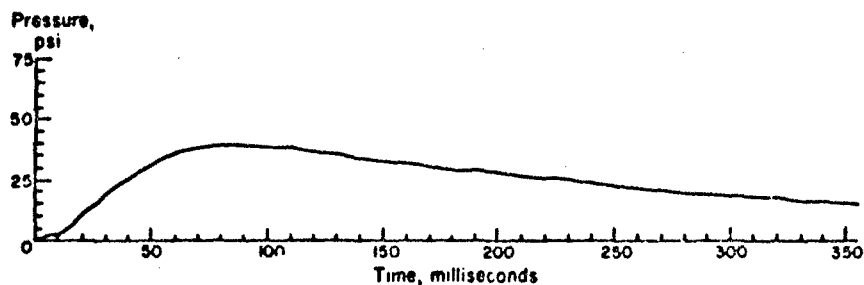
Scale in feet
0   2   4   6

P_d 70 psi
P_m 31.3 psi
T_{P_m} 87 msec
T_d .765 sec

Expansion
Chamber   Gauge   Closed
Baffle   Diaphragm
Open

Compression Chamber

ARRANGEMENT 4

Pressure-Time Record
Arrangement 13

Pressure, psi

100
80
60
40
20
0

0   10   20   30   40   50   60   70   80   90   100   110   120

Time, milliseconds
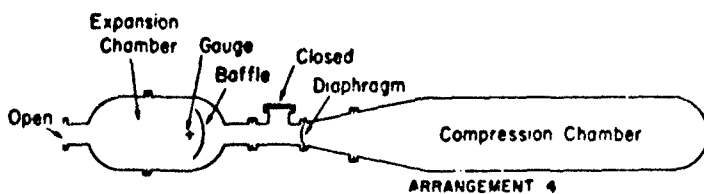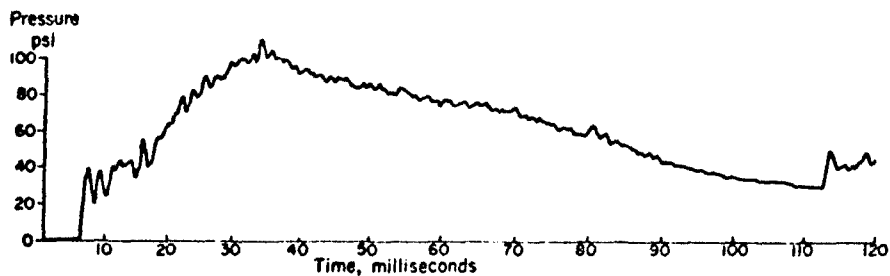
Scale in feet
0   2   4   6

P_d 100 psi
P_f 40 psi
P_m 102 psi
T_{P_m} 35 msec
T_d 5 sec

Gauge   Diaphragm

3'-4"   25'-0"
Expansion Chamber   Compression Chamber
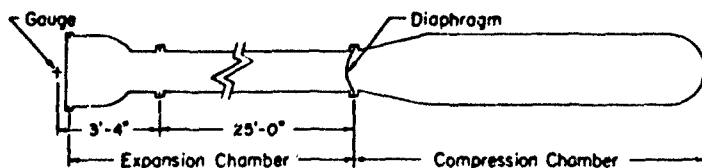
ARRANGEMENT 13

Figure 8. Shock-tube arrangements that produced slow, smooth-
rising pressure curves (upper portion) and a combination
of sharp-rising and slow-rising pressures (lower portion).

-13-

Larger species are more tolerant to a given pressure pulse than are the smaller ones.

Representative dose-response curves for six mammalian species exposed to sharp-rising pressures of 400-msec duration are presented in Figure 9.[4] On a regular plot, the curves are typically s-shaped. Here they have been plotted as the per cent mortality (in probit units) against the log of the dose; in this case, the reflected shock pressure. Also listed in Figure 9 are the LD_{50}-24-hour values which can be seen to range from 30.7 for the 20-g mouse to 53.0 psi for the 20-kg goat.

These LD_{50} values are plotted in Figure 10 against the corresponding body weight of the species. This form of interspecies correlation has been extrapolated to predict an LD_{50} of 50 psi for mammals of 70-kg body weight — in the weight range of man. It should be pointed out that the 50-psi figure applies to the 400-msec-duration pulse as illustrated in Figure 4. The constant lethality curves presented in Figure 11, relating LD_{50} pressures as a function of duration for six species, provided the information from which five other such interspecies correlations were performed at other durations.[11] In Figure 12, a curve fitting these extrapolated LD_{50} points for the 70-kg animal is presented along with the corresponding LD_1 and LD_{99} values. Thus, the estimated tolerance curve of the 70-kg animal is above, but of a similar form to those for the experimental animals. The tolerance would be lowest at the longest duration and climb at an increasing rate as the duration becomes sufficiently short. At the longer durations, the peak pressure appears to be the significant physical parameter of the blast wave associated with lethality; whereas, for the ascending portion of the curve in the short-duration region, both peak pressure and duration are definitive for mortality.

It must be emphasized that these predicted values represent a rather crude first approximation. Like all extrapolations, particularly biological ones, considerable leeway should be allowed; however, it is the best currently available and is based on studies involving approximately 3,000 experimental animals. Finally, from the information at hand, it would appear that these curves may be applied to incident or to reflected shock pressures of equivalent magnitude provided they are sharp-rising. They do not apply to other wave forms because, as will be pointed out subsequently, animal resistance to many atypical wave forms is much higher.

Biological Tolerance to Pressures that Rise in Steps

Personnel located within structures or in the open near reflecting surfaces would be subjected to air-blast waves that rise initially in two steps. It has been found with experimental animals that resistance to step-rising pressures is higher than that for a single sharp-rising pulse of equivalent magnitude, provided a sufficient time occurs between the steps.[6-8,11-16] The distance one is from the reflecting surface is therefore critical. For example, the LD_{50} reflected pressure for guinea pigs rose from 35 - 40 psi to 55 - 60 psi when the time between the incident and reflected shocks was
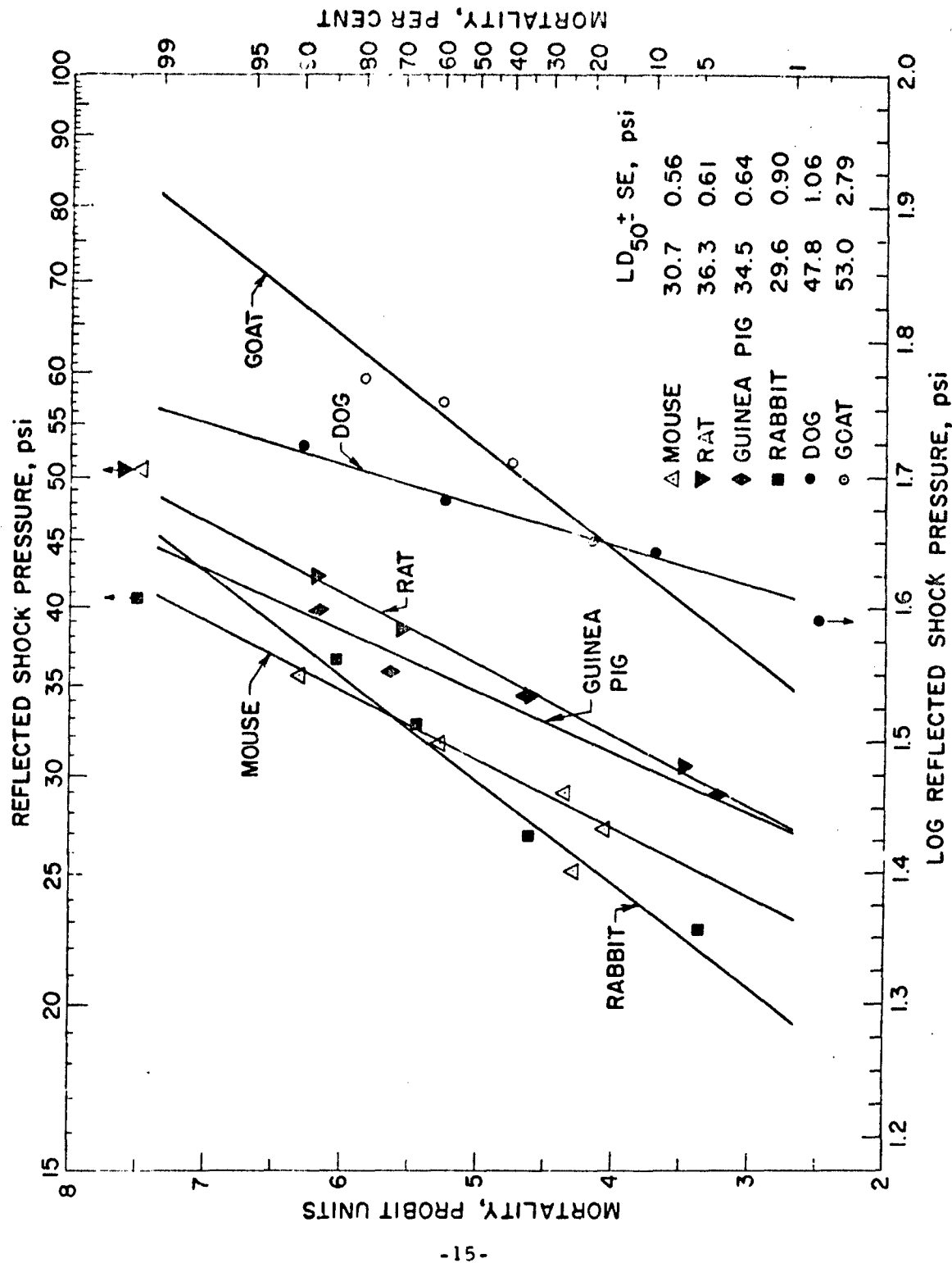
Figure 9. Dose-response curves and LD50 values for six species exposed on the end-plate of a shock tube to sharp-rising overpressures of 400-msec duration.[4]

Relation Between Body Weight and Fast-Rising
Overpressures of 400 Milliseconds Duration
Needed to Produce 50 Per Cent Mortality
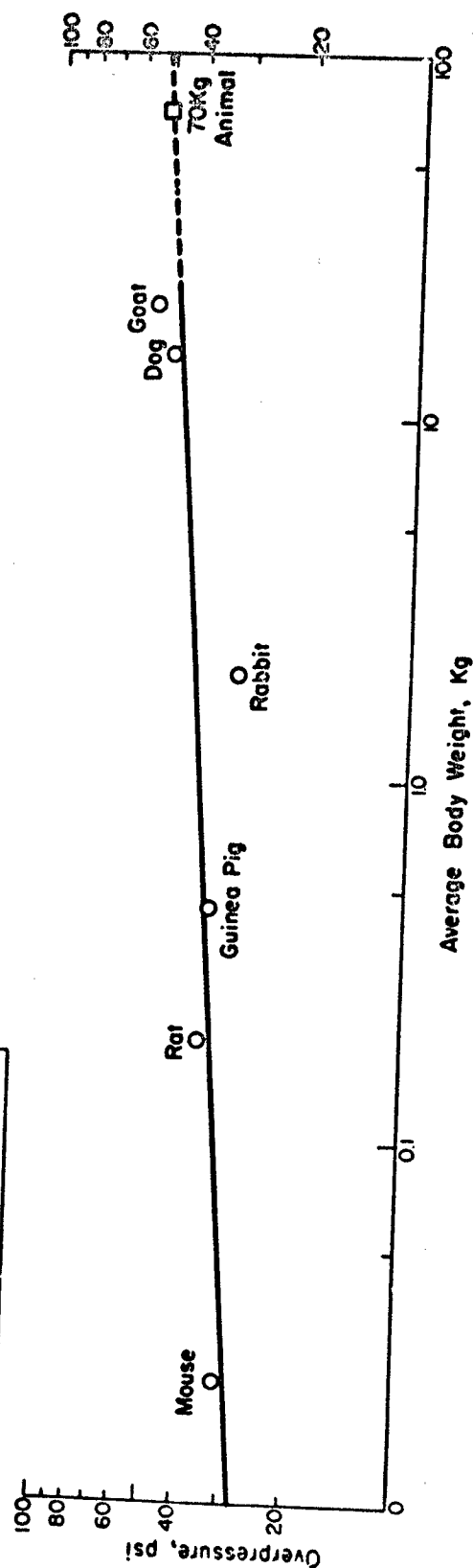
Figure 10. Interspecies correlation extrapolated to animals in the weight range of man. Regression equation: $\log y = 1.3673 + 0.06939 \log x$, where $y = LD_{50}$ in psi and x = body weight in grams. Standard error of estimate: 0.0602 log units (13.9 per cent).4

-16-
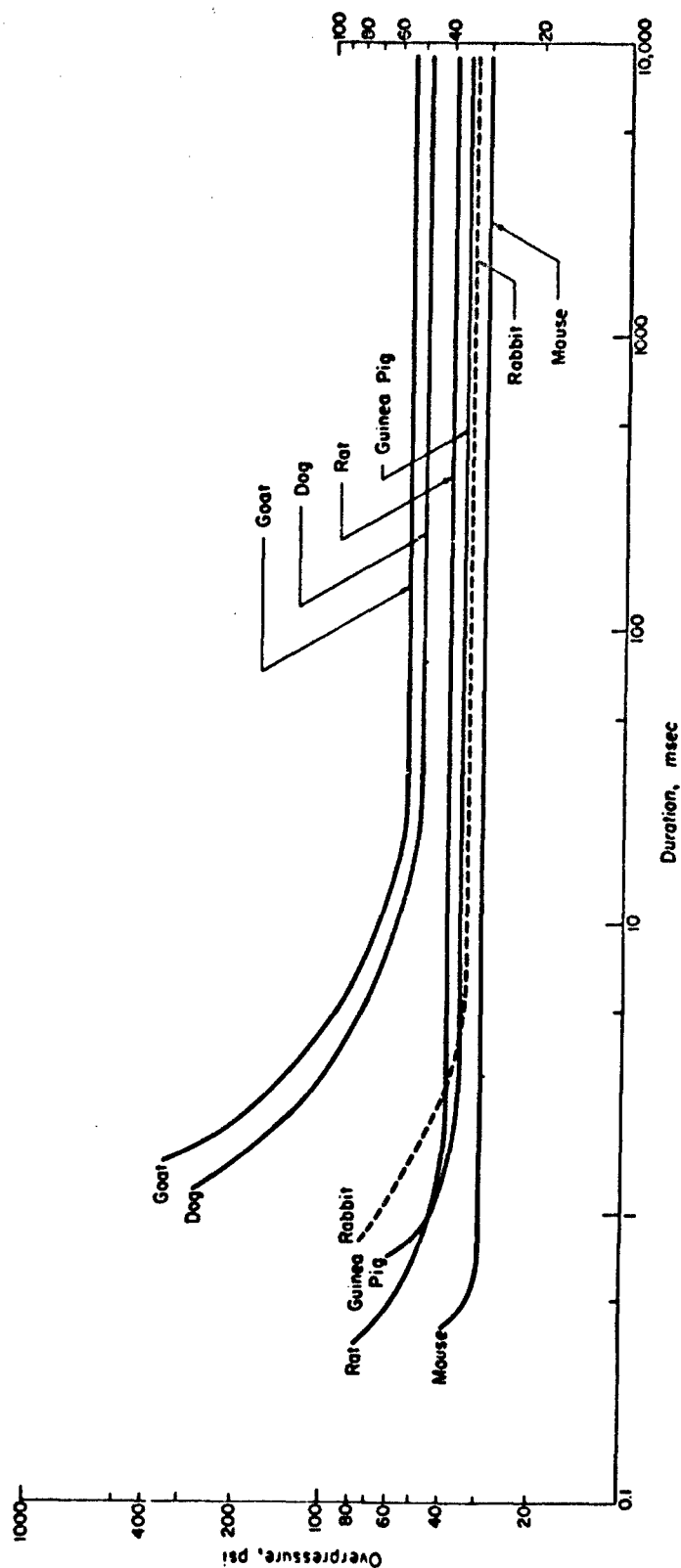
Figure 11. Fifty-per cent constant lethality curves for six species relating
pressure to duration.11

The Overpressure-Duration Relationship
calculated for 1, 50 and 99% lethality
for the 70Kg mammal.
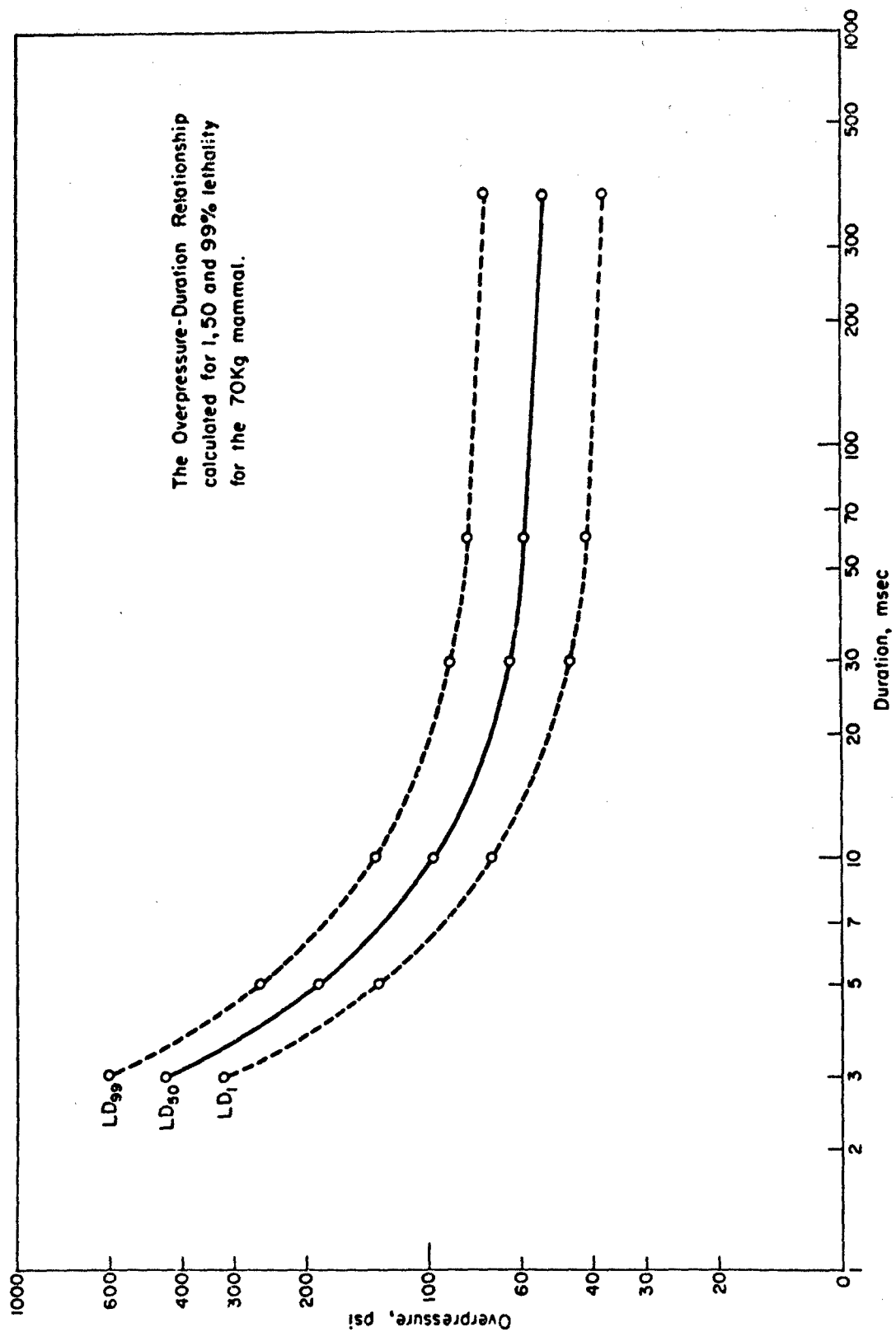
Figure 12.   Constant lethality curves predicted for animals in the weight
range of man from extrapolating interspecies-response data.[11]

increased beyond 0.2 msec — about 2 in. from the reflecting surface as measured to the downstream side of the animal (Figure 13). The critical time interval appears to be related to animal size. It was longer for the dog as shown in Figure 13, being 0.5 msec and less than 0.2 msec for small animals such as mice and rats.[11]

Man's tolerance to step-rising overpressures therefore would be expected to increase by 50 per cent or more above that for single step-rises, provided a sufficient time occurs between steps. Unfortunately, there is not enough step-load information available for larger animal species to enable one to estimate the time-step (or distance from a reflecting surface) significant for man.

Biological Tolerance to Smooth-Rising Pressures

Animals can tolerate surprisingly high overpressure when the time to maximal level is beyond a few tens of milliseconds providing the pressure rises smoothly. Dogs survived with just trivial injuries from long-duration overpressures of from 86 - 167 psi that rose to a maximum in 150, 90, 60, and 30 msec (Table 1).[9] The animals were held in place by a harness arrangement and were behind a protective wind baffle to prevent them from being blown about in the test chamber. The injuries caused by the high pressures were eardrum rupture, hemorrhagic paranasal and frontal sinuses, and small hemorrhagic areas in that peripheral portion of the lung located at the lateral junctions of the diaphragm and the rib cage. The highest pressures were three- to fourfold those that would be lethal if the pulse were sharp-rising.

That animals can tolerate very high pressure applied in a smooth, "slow" fashion can be well illustrated by the data of Wünsche and Schardin in Figures 14 and 15.[17] Rats were exposed in a pressure vessel to 28, 33, 37, 43, and 46 atm with time to maximal pressure in each instance kept at 0.5 - 0.6 sec. No deaths occurred at 28 atm. In fact, it was concluded by the investigators that the mortality which occurred at 33 atm and above was related to a combination of the time held at the high pressure (t_2) and the time of pressure decay (t_3), and not to the initial loading, per se. Similar findings have been reported by Lee et al. for mice.[18] Pressure of 40 - 70 psi applied in 6 sec resulted in lethality which was related to both the hold time and rate of decompression.

It appears that high pressures rising in a smooth manner do not pose a serious hazard to personnel from the primary effect; however, it should be emphasized that translational effects indeed would occur as a consequence of the high flow associated with such marked pressure changes.

Biological Tolerance to Other Wave Forms

When one considers the infinite number of structure geometries possible, variations of pressure-time patterns are almost unlimited. However, as the reader is aware by now, the hazards associated with overpressure itself
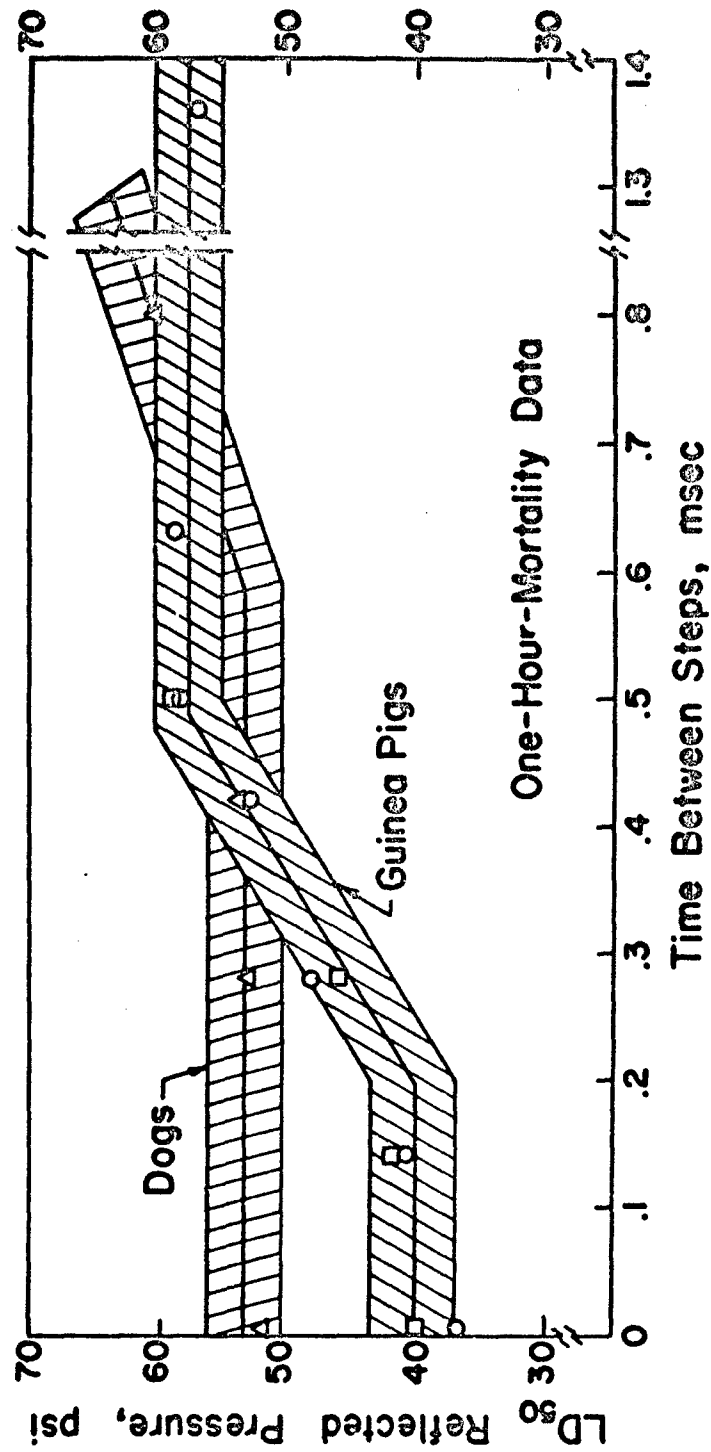
Figure 13. Increased resistance to overpressure shown when animals are moved upstream from a reflecting surface which increases the time between the application of the incident and reflected shock front.[11]

TABLE 1

EFFECTS OF SLOW-RISING OVERPRESSURES
OF LONG DURATION ON DOGS*

Max. Overpressure, psi	Time to Max. Pressure, msec	Duration of Overpressure, sec	Damage Observed[+]		
			Ruptured Eardrums	Hemorrhagic Sinuses	Lung Contusion
167	155	5	Yes	Yes	None
118	85	20	Yes	Yes	None
156	86	20	Yes	Yes	Minimal
170	60	10	Yes	Yes	None
86	28	10	Yes	Yes	None
130	30	10	Yes	Yes	Minimal

*Data from Richmond et al.[9]
[+]All animals survived.
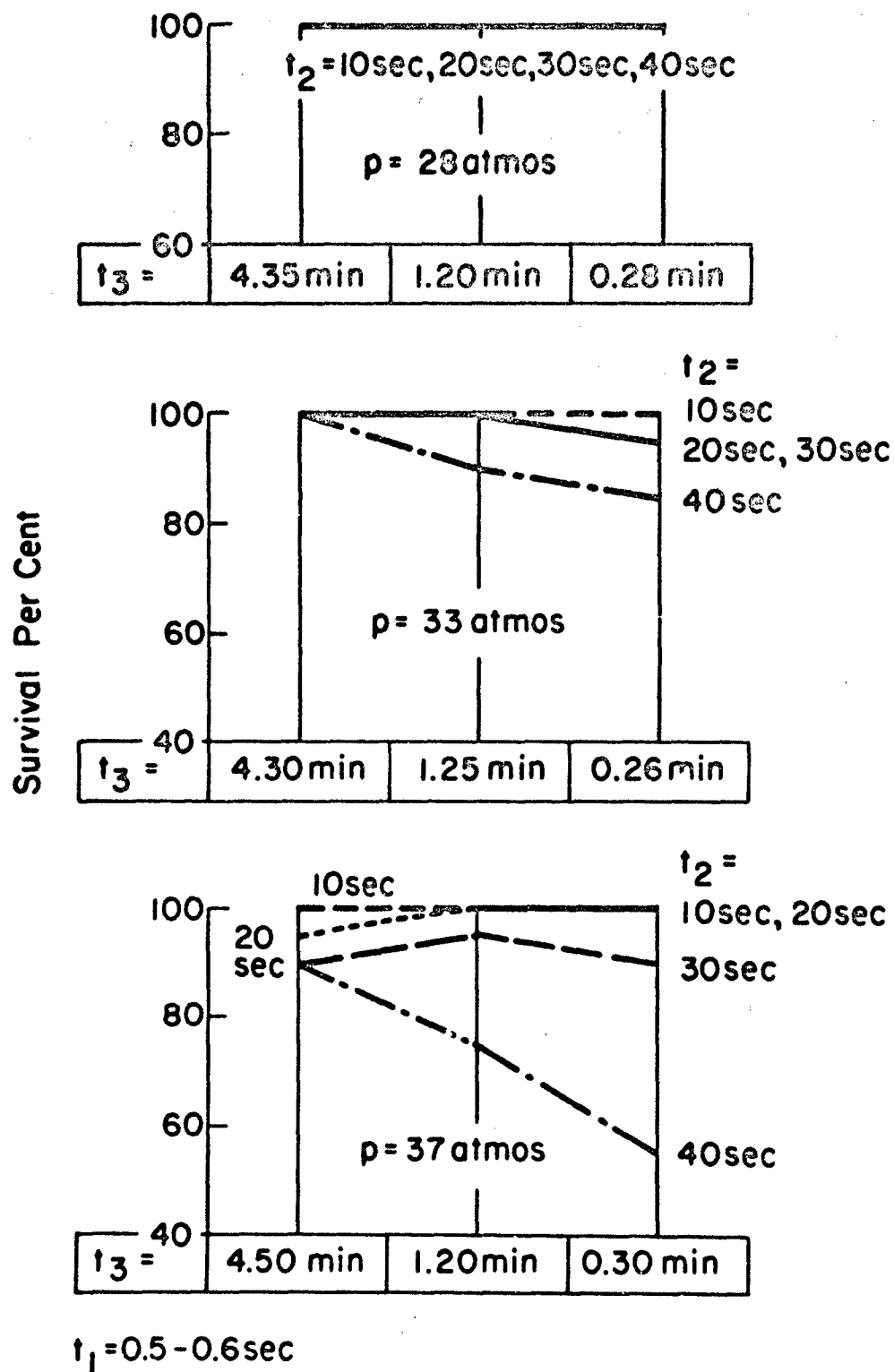
from Schardin

Figure 14. Percentage of rats surviving slow, smooth-rising over-
pressures of 28, 33, and 37 atm with time to maximal
pressure of 0.5 - 0.6 sec. Times held at pressures (t_2)
varied from 10 - 40 sec with time of decompression
(t_3) of from 0.26 - 4.50 min. [17]
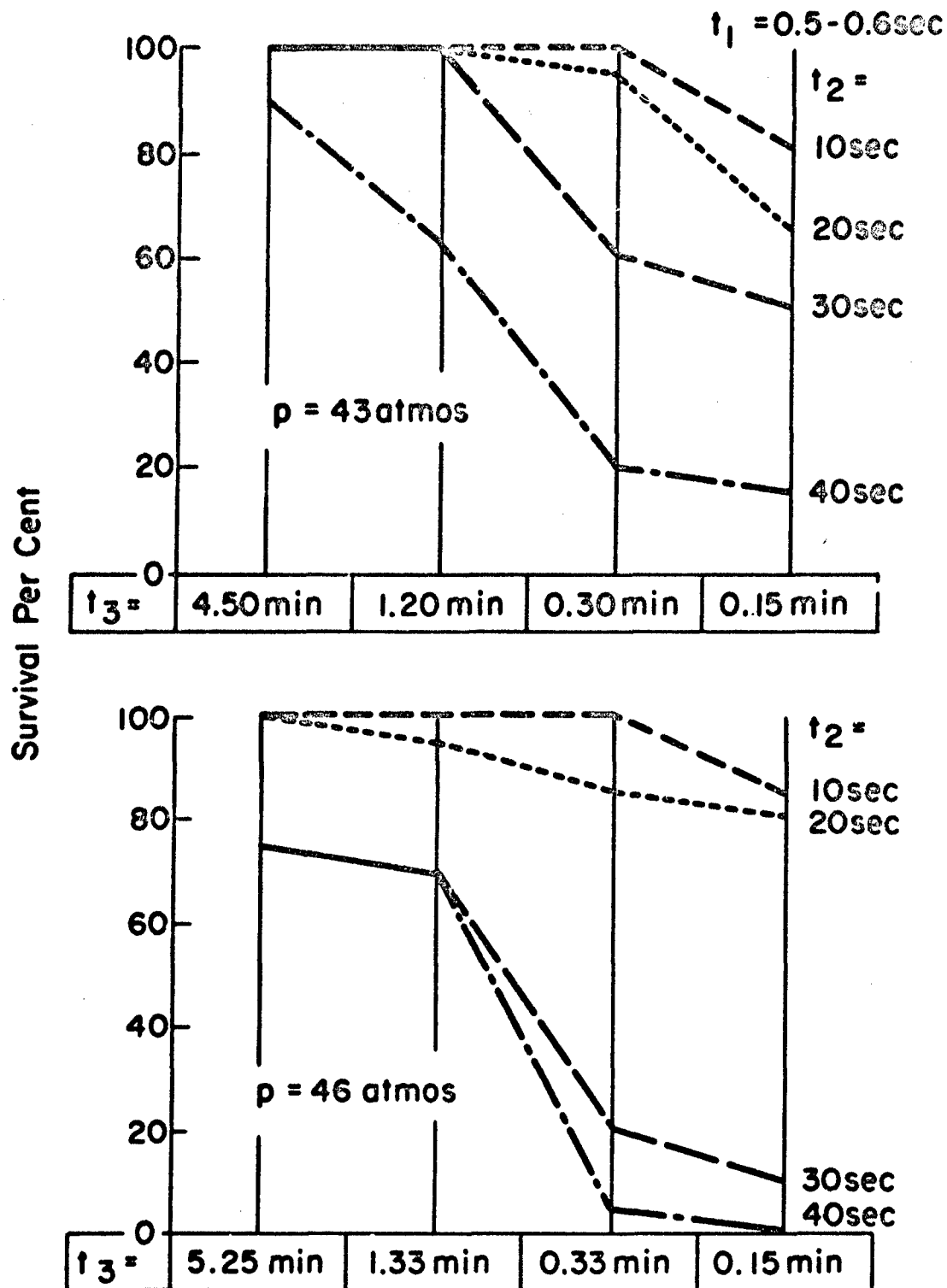
from Schardin

Figure 15. Percentage of rats surviving slow, smooth-rising overpressures of 43 and 46 atm with time to maximal pressure of 0.5 - 0.6 sec. Times held at pressure (t_2) varied from 10 - 40 with times of decompression (t_3) of from 0.15 - 5.25 min.[17]

depend greatly upon the character of the leading edge of the pulse. For instance, a common pressure-time pattern is that recorded in the group shelter and the basement-exit shelters (Figures 1 and 2). The early portion of the pulse contained the incident and multiple reflections of the shock which were followed by a crown or rather smooth increase in pressure to a maximal value. The foregoing remarks regarding sharp-rising pressures that rise in one or several steps can be applied here, for example, those wave forms recorded in the group and basement-exit shelters (Figures 1 and 2). Since the magnitude of the incident and reflected shocks at the initial portions of the records did not go much above 10 psi in a single step, one would not expect significant injury to occur even in mice. In those instances where early reflections did occur and reached significant levels of 30 - 40 psi (fast-fill room of group shelter and basement-exit shelter one-half open, Figures 1 and 2, respectively), rather long time periods occurred between steps (shocks). Regarding the crown or subsequent, slow, smooth-rising pressure, it does not appear particularly damaging, with two possible exceptions. First, it can produce eardrum rupture and hemorrhagic sinuses which, unlike the other primary injuries, appear to be related simply to the maximal pressure and all available data indicate that the wave form is not an important factor.[1,2,19,20] Second, although the pressures in the shelters did not climb to particularly high levels, it has been reported that blow-out fractures of the orbit will result in dogs when, with wave forms of this type, the pressure goes above 140 psi in less than 30 msec following the initial shocks.[13] This lesion results from the eyeball transmitting the pressure hydraulically to the thin bones lining the orbit and fracturing them. The incidence of this lesion was low and may or may not be produced in man from air pressure.

Finally, a word about two other parameters of the blast wave. First, the reader will recall that the reflected shocks appear to oscillate in the confined spaces of shelters. Little or no information is available on the biological effects of repeated shock or oscillating pressure pulses. However, one might expect damage to the body at pressures of fairly low magnitude oscillating at a frequency that matches the natural period of the body. Second, it is generally agreed that the negative phase of the blast wave itself is not involved in primary blast injury. Nevertheless, this does not mean that the combination of pressure-loading and pressure-release may not be significant in explaining the exact mechanism of injury which will not be considered here.

Range-Yield-Effects Relationships for Primary Blast Effects

Based on information such as that presented above, it has been possible to formulate tentative criteria for the primary effects on man for "fast"-rising overpressures of long duration.[2,21-24] Table 2 indicates the incident shock pressures (no reflections) and the incident shocks (with maximal reflections) required for threshold of lung injury, eardrum rupture, and lethality as well as 50- and near 100-per cent mortality levels.*

---

*The reflected overpressures were computed following Glasstone's Effects of Nuclear Weapons, 1962 Edition.[26]

TABLE 2

TENTATIVE CRITERIA FOR PRIMARY BLAST EFFECTS IN ADULTS APPLICABLE TO "FAST"-RISING, "LONG"-DURATION OVERPRESSURES IN AIR

(Modified from References 2, 24, 25)

Critical Organ or Event	Related Maximum Overpressure, psi	
	Maximum Effective at Target	Incident with Maximum Reflection
Eardrum Failure*		
Threshold	5	2.3
50 per cent	15 - 20	6.2 - 8.0
Lung Damage+		
Threshold	10 - 12	4.4 - 5.1
Lethality†		
Threshold	30 - 42	11 - 15
50 per cent	42 - 57	15 - 18
Near 100 per cent	57 - 80	19 - 24

*Data from Zalewski,[19] WT-1179,[1] CEX-65.4,[2] WT-1467,[20] Richmond.[15]
+Data from CEX-65.4,[2] Richmond.[15]
†Data from CEX-58.8,[22] DASA 1341,[25] CEX-63.7,[23] DASA 1335.[11]

NOTE: The lung and lethality data, derived using shock tubes in Albuquerque at 12 psi using a side-on exposure geometry against a reflecting surface, apply strictly to such conditions wherein the maximal reflected pressure was the maximal effective pressure. There may be enough evidence soon to scale the data to sea level and to other geometries of exposure.

These criteria are presented in Figure 16 as a function of range and yield from 1 kt to 100 Mt.[24-26] The four lower curves show the range as a function of yield for the incident overpressure with no reflections necessary for the effect. The four upper curves relate the ranges when maximal reflection would result. These represent the free-field (in-the-open exposure) and the "worst" geometry of exposure; namely, one in which the incident shock reflects to a maximum. The latter, there fore, would extend those hazards to greater ranges from a given yield explosion.

SECONDARY BLAST EFFECTS

General

The secondary effects depend primarily upon the mass and velocity of the debris (missiles) at impact and the portion of the body struck. Further, missile shape and orientation, as well as the angle of impact, and whether or not penetration of the skin and body wall occurs, help dictate the biological consequences.

Personnel, if located in a building, may experience anything from a shower of window-glass fragments to massive crushing injury from collapse of the entire building. In the open, they may sustain the impact of building debris, small stones, twigs, or large tree fragments. The nature of the injuries would parallel those already encountered in bombed cities. Reported have been skin lacerations, bruises, fractures, internal injuries in the form of organ rupture, and the like. These, although quite varied compared to the definite syndrome for primary effects, are not unlike those traumatic injuries common to the battle field and to our modern society and, of course, can be quite severe and rapidly lethal.

Missile Velocities and Biological Response

On nuclear tests in Nevada, glass fragments were trapped behind windows in typical houses that were located between one and two miles from a 29-kt burst.[27-28] It was found that glass fragments developed impact velocities of between 50 and 400 ft/sec. The average velocities and masses of these along with their spatial densities for incident pressures of 1.9, 3.8, and 5.0 psi are given in Table 3. It can be seen that at higher pressures the glass missiles were smaller, attained higher velocities, and occurred in greater density. It can also be seen in Table 3 that small stones developed velocities as high as 346 ft/sec at the 8.6 psi range, but up to 731 ft/sec at a location where 15.2 psi was measured.

Related laboratory tests determined the velocities required for glass fragments to penetrate the abdomen of dogs (Table 4).[28] As an example, a 1-g piece of glass could be expected to penetrate the abdomen of a dog 1, 50, and 99 per cent of the time if the velocity was 140, 245, and 430 ft/sec,

RANGE-YIELD RELATIONSHIP for
INDICATED PRIMARY BLAST DAMAGE; SEA-LEVEL SURFACE BURSTS
Applies to Fast-rising Overpressures with Ideal or Near-ideal Wave Forms
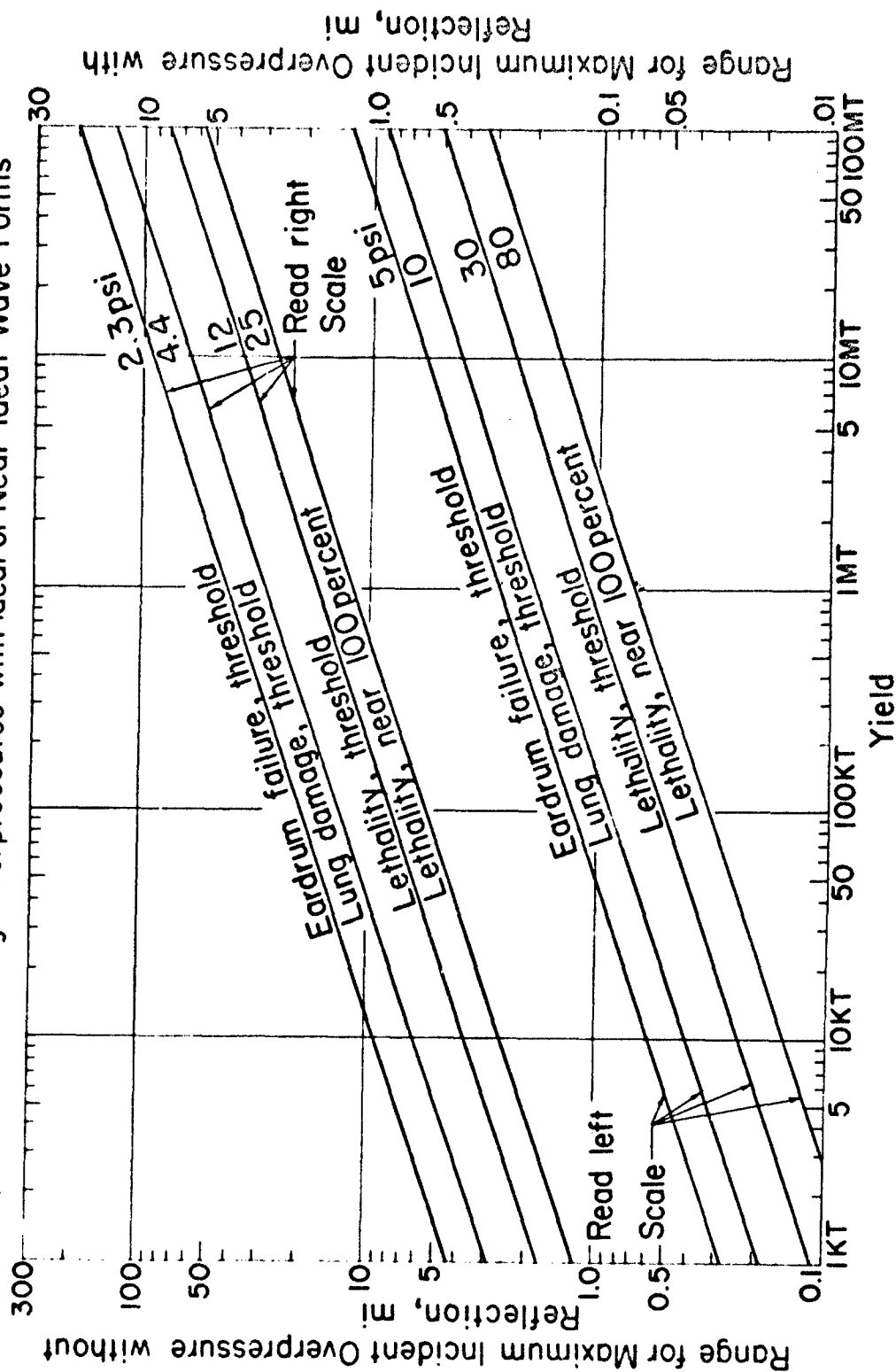
Figure 16

TABLE 3

VELOCITIES, MASSES, AND DENSITIES OF MISSILES*

Max. Pres., psi	Type of Missile	Geometric Mean (Range) Velocity ft/sec	Geometric Mean (Range) Mass g	Max. Missile Density, missiles/sq ft
1.9	Window glass	108 (50-178)	1.45 (0.03-10)	4.3
3.8	Window glass	168 (60-310)	0.58 (0.01-10)	159
5.0	Window glass	170 (50-400)	0.13 (0.002-140)	388
8.6	Natural stones	181 (98-346)	0.08 (0.013-2.63)	3.1
15.2	Natural stones	459 (412-731)	0.52 (0.060-14.52)	32
15.2	Natural stones	432 (300-384)	0.21 (0.010-13.4)	99.1

*Data from WT-1168,[27] AECU-3350,[28] and WT-1468.[29]

TABLE 4

PROBABILITY OF GLASS FRAGMENTS PENETRATING THE ABDOMINAL WALL OF DOGS*

Mass of Glass Fragments g	Impact Velocities for Indicated Probabilities of Penetration in Per Cent ft/sec		
	1 per cent	50 per cent	99 per cent
0.05	320	570	1000
0.1	235	410	730
0.5	160	275	485
1.0	140	245	430
10.0	115	180	355

*Data from Bowen et al.[28]

respectively. For fragments less than or greater than 1 g, higher and lower velocities, respectively, would be required for penetration. Further, it has been estimated that 10-g glass fragments impacting at 50 ft/sec would cause skin lacerations and probably would present a special hazard to the eyes.

Laboratory studies have pointed out that serious internal injury can be caused from 0.8-lb and 0.4-lb nonpenetrating missiles striking the lateral chest wall of dogs at 45 and 80 ft/sec, respectively, and that death may result if the velocities are 155 and 170 ft/sec, respectively (Table 5).[22,30] In all probability, rupture of the liver, kidney, or spleen would result when similar blunt objects strike the lateral or ventral abdominal area at corresponding velocities.

According to the other data in Table 5, human skull fracture can be produced from the blow of a 10-lb object going 15 to 23 ft/sec.[31] One is reminded of the scope of this problem by noting that building materials dislodged by the air blast or ground shock need only free-fall 3.5 to 8.3 ft to develop velocities of 15 to 23 ft/sec from gravity alone.

Range-Yield-Effects Relationships for Secondary Blast Effects

Table 6 summarizes the velocities predicted for 10-g glass fragments to produce skin lacerations and serious, penetrating wounds for man.[20-23]

Mathematical models based on empirical data from the full-scale tests and laboratory experiments allowed computations of the velocity-mass-distance-time relationships making it possible to estimate range-yield combinations for which 10-g glass fragments would develop the velocities associated with the above-stated biological effects.[32] These are plotted in Figure 17 for a translational distance of 10 ft. It was assumed in the computations that the structure or the wall containing the glass window faced the blast wave and that the overpressure would undergo reflection. This was necessary because the input data from the Nevada operation showed this to be the case. It can be seen in Figure 17[24] that at a distance of slightly over a mile from a 100-kt burst there could be a near 100-per cent incidence of serious wounds from glass fragments hurled at 300 ft/sec. It should be pointed out that at this pressure level (near 5 psi) most ordinarily constructed homes would be destroyed, and one might expect other overriding hazards associated with the collapsed buildings.

TERTIARY BLAST EFFECTS

General

Though man hurled through the air may be damaged because of differential displacement of different portions of the body during the general process of acceleration, it is known that the decelerating surface, the angle and area of the body involved at impact, the impact velocity, and the decelerating

TABLE 5

EFFECTS OF MISSILE IMPACT ON THE CHEST AND HEAD

Biological effects observed	Threshold velocities for missiles of indicated weights, ft/sec	
	0.8 lb	0.4 lb
Lung hemorrhages*		
Side of impact only (unilateral)	45	80
Impact side and opposite side (bilateral)	110	125
Rib fracture*	60	120
Internal lacerations from fractured ribs*	90	120
Fatality within 1 hr*	155	170
Experimental fracture human skull[+]	15 to 23 ft/sec range of velocities for 10-lb object (7-15 lb weight range of human adult head)	

*Unpublished data from dogs, AEC Project, Lovelace Foundation, Albuquerque, N. M.[22,30]
[+]Computed from data of Gurdjian et al.[31]

TABLE 6

TENTATIVE CRITERIA FOR SECONDARY BLAST EFFECTS

Critical organ or event	Related velocity for 10-gm glass fragment ft/sec[+]
Skin laceration*	
Threshold	50
Serious wounds*	
Threshold	100
50 per cent	180
Near 100 per cent	300

*Data from AECU-3350.[28]
[+]Figures represent impact velocities with unclothed biological target.

RANGE-YIELD RELATIONSHIP for INDICATED SECONDARY BLAST DAMAGE from
10-gm WINDOW-GLASS FRAGMENTS* for SEA-LEVEL SURFACE BURSTS

Applies to ideal or near-ideal wave forms

Skin lacerations, threshold
Serious wounds, threshold
Serious wounds, near 100 percent

50 ft/sec*
100*
300*

Computed for 10-gm fragments of double-strength window glass, p_o=14.7 psi, c_o=1117 ft/sec; acceleration coefficient=0.72 sq ft/lb
*when translational distance=10 ft

Range, mi

Yield

Figure 17

-32-
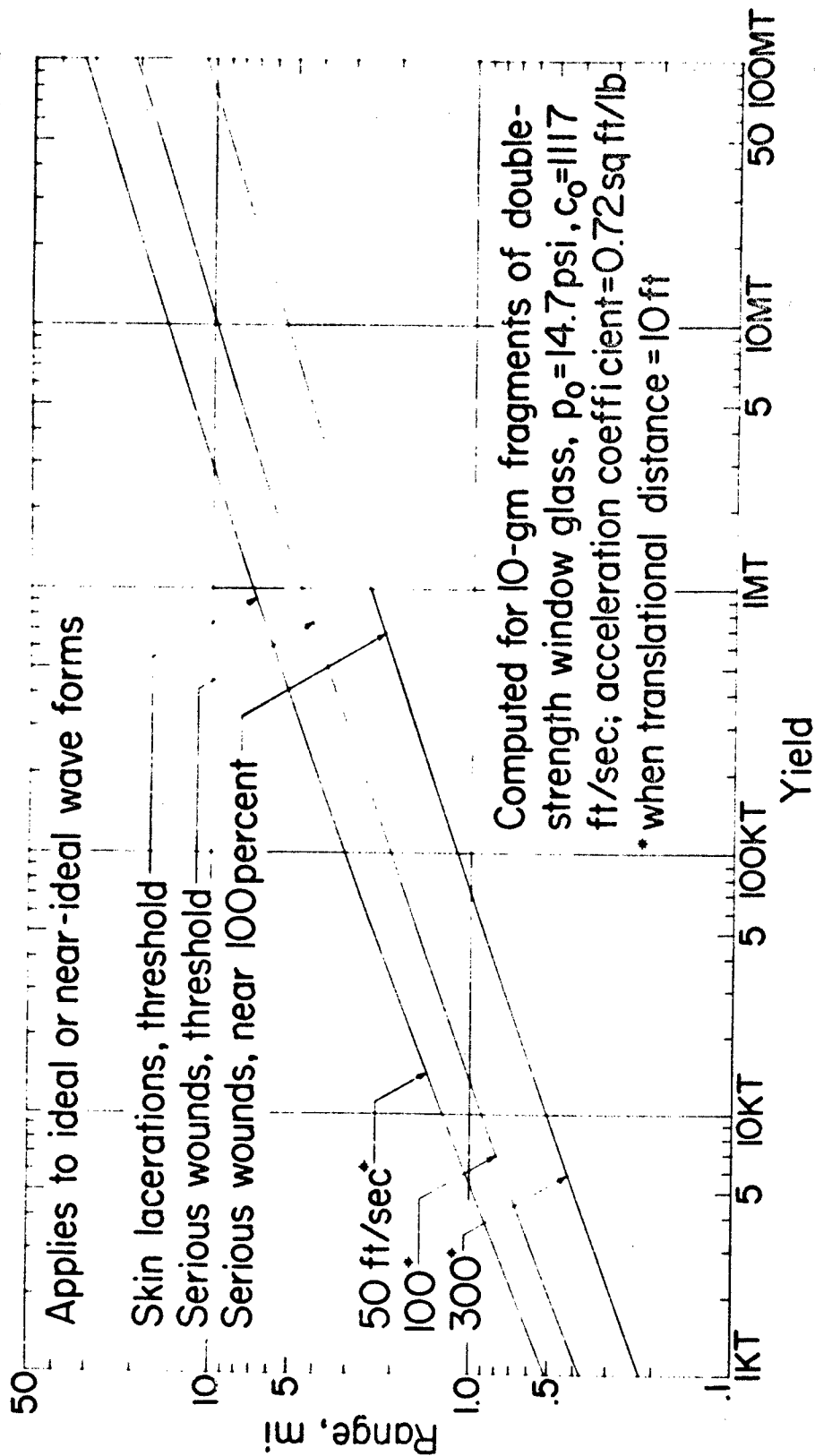
time and distance are each critical factors. Most hazardous of all (with certain rare exceptions) is, in all probability, uncoordinated impact against a hard surface.

As the reader would suspect, the injuries resulting from blast-produced impacts could be expected to follow the same pattern encountered in victims of falls, automobile and aircraft accidents, and the like; for instance, laceration and contusion of the soft tissues and skin, skeletal fracture, and rupture of internal organs including the large blood vessels and the heart. In fact, analysis of records pertaining to accidental falls has added to our understanding of man's tolerance to unrestrained impacts. Consequently, the velocity at impact, in ft/sec, has been taken as the physical parameter to describe the "dose" for impact.

Blast Displacement of Anthropometric Dummies

The following information, taken from motion picture records of dummies during a nuclear blast, will well illustrate the magnitude of the parameters involving tertiary blast effects. [33]

Figure 18 presents the time-displacement history for a 165-lb dummy exposed standing back-on to the blast at the 5,320-ft range from a 38-kt detonation in Nevada. The blast wave was ideal with a peak pressure of 5.3 psi and of 964-msec duration. The maximal acceleration was between 4 and 5 g-units. The dummy reached a maximal velocity of 22 ft/sec in about 0.5 sec, at which time it had moved a little over 8 ft. In 0.1 sec, the dummy was already moving 13 ft/sec and had traveled about 0.9 ft. The dummy went 13 ft through the air, hit the ground, and slid or bounded 9 ft more — going approximately 22 ft altogether. It is clear from this data that one must recognize the distance a body can travel during translation because, if impact occurs before or after reaching maximal velocity, the forces on the body will be less severe.

A second dummy, lying prone and head-on alongside the standing one, was not moved by the blast (Table 7). This emphasizes the importance of one's orientation (presented area) to the blast wave which can markedly reduce the tertiary hazards under some circumstances.

Also in Table 7 are results of another experiment with dummies located at the 6.6-psi line and 3,406 ft from a 44-kt detonation. [33] In this instance, motion picture records were not obtained for detailed analysis. The standing dummy was translated 265 ft and the prone dummy, 124 ft. The greater distance of travel was due to an atypical wave form with a very high dynamic pressure of 15.8 psi compared with the 0.7-psi dynamic pressure that occurred in the 5.3-psi experiment.

From the results of these tests, Bowen et al. [32] have developed a mathematical model that allows calculating the time-displacement histories for "man" for ideal blast waves of other magnitudes and durations. It remains then to answer the questions regarding the biological hazards associated with these translational velocities.
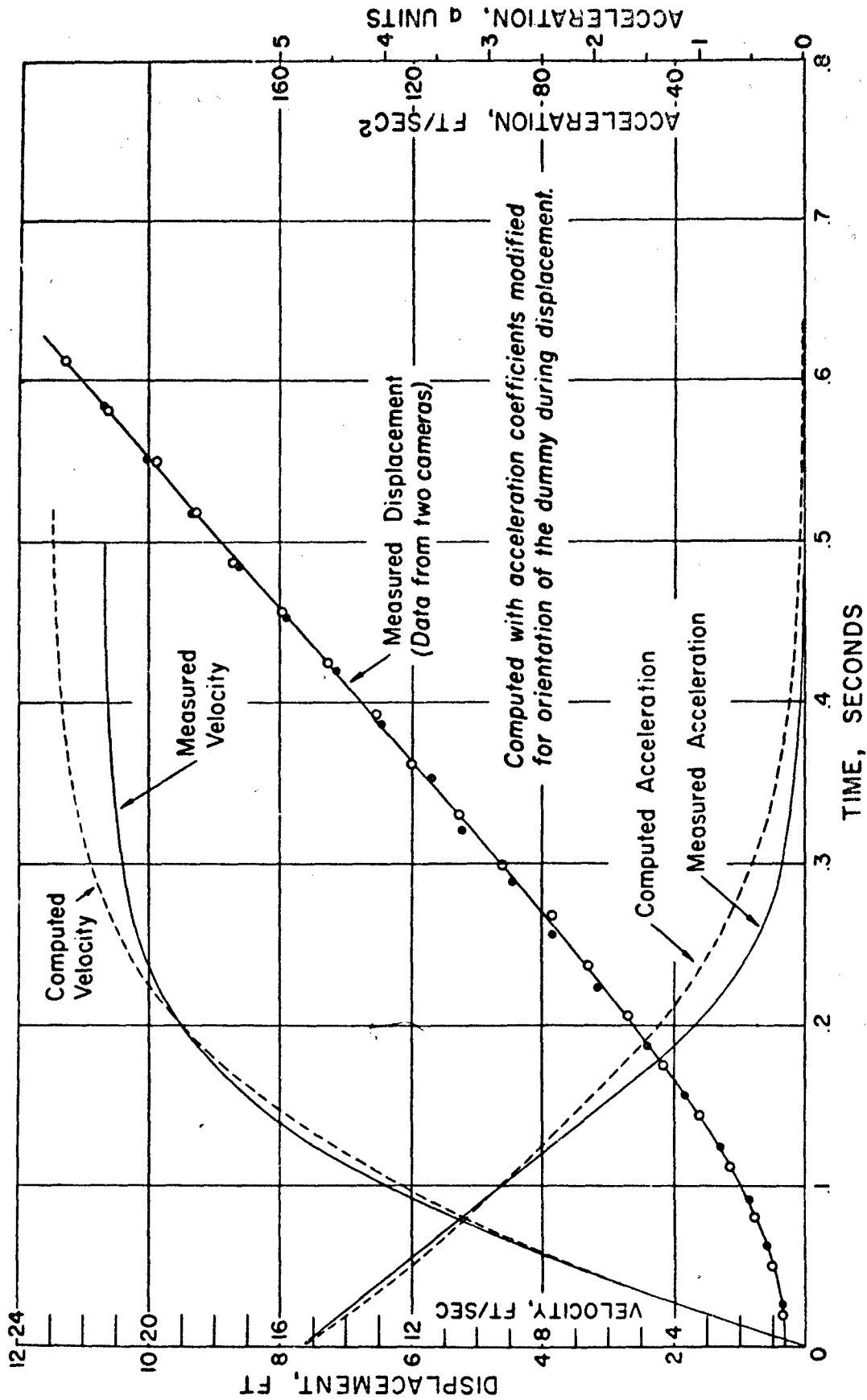
Figure 18. The velocity-time and distance relationship for a standing dummy subjected to an ideal nuclear wave of 5.3 psi. 21,33

TABLE 7

BLAST DISPLACEMENT OF 165-LB
ANTHROPOMETRIC DUMMIES*

Max. Pressure, psi	Max. Q, psi	Pressure Duration msec	Initial Dummy Position	Displacement, ft
5.3	0.7	964	Standing	21.9
			Prone	None
6.6	15.8	868	Standing	256
			Prone	124

*Data from Taborelli and Bowen.[33]

Biological Response to Impact

Hard-Surface Impacts

Interspecies studies were undertaken to compile dose-response curves which related impact velocity against a hard surface to lethality.[34] Impact velocities were generated by allowing animals to free-fall from various heights onto a concrete slab. It can be seen in Table 8 that the impact velocities for 50-per cent mortality were 38, 44, 31, and 31 ft/sec for the mouse, rat, guinea pig, and rabbit, respectively. These values, when extrapolated simply on a body-weight basis to animals of 72.6 kg, predicted that 50-per cent lethality would occur at impact velocities of 26 ft/sec (18 mph). Further, it was calculated that 1-per cent and 99-per cent lethality may be expected with impact velocities of 20 and 30 ft/sec or about 14 and 20 mph, respectively. Since these figures, extrapolated from the interspecies study, were in general agreement with relevant data reported for man, they have been adopted tentatively as the criteria for tertiary effects.

A few of these data can be noted in Table 9. First, Gurdjian et al.,[31] using human material, determined the relation between impact velocity and the incidence of skull fracture. According to his data, impact velocities of about 14 to 23 ft/sec resulted in the fracturing of cadaver heads dropped on a hard, flat surface from 1 to 99 per cent of the time. Second, the data of Draeger et al.[35] shows that fracture of the feet and ankles of cadavers occurred at impact velocities of 12 to 13 ft/sec when they were in the "knees-locked" position. Third, fracture of the lumbar spine was estimated to occur at impacts of 8 ft/sec for man dropped just one ft in the sitting position onto a hard surface.[36]

That personnel would be particularly vulnerable to impact-type deceleration was obvious from some automobile accident statistics reported by De Haven.[37] He found 40-per cent lethality to be associated with estimated vehicular speeds of 30 mph or less (44 ft/sec) and 70-per cent lethality with speeds of 40 mph or less (59 ft/sec). Regarding whole-body impact, Swearingen et al., in experiments with human volunteers, reported that impact velocities of 10 ft/sec were tolerated both in the sitting and standing positions.[38] Therefore, for most situations, 10 ft/sec has been taken to be a "safe" impact velocity for man.

Tumbling and Sliding Impacts

Personnel, exposed in the open, probably would experience impacts in the form of tumbling and sliding. In this case, one feels intuitively that much higher velocities could be tolerated than those for impacts with hard, flat surfaces providing, of course, no solid objects (such as rocks or trees) were encountered or the body was not thrown upward. Regarding tumbling, the work of Anderson et al. is pertinent.[16] They have reported no injuries in goats that were shot from a shock tube at velocities ranging from 0 to 30 ft/sec and tumbled over an open, grassy pasture. Not until velocities

TABLE 8

VELOCITIES OF IMPACT AGAINST A HARD SURFACE ASSOCIATED WITH 50-PER CENT MORTALITY OF THE INDICATED SPECIES OF ANIMALS WITH EXTRAPOLATED VALUES FOR MAN*

Species of Animal	Animal Mass g	Impact Velocity for 50-Per Cent Mortality		Equivalent Height of Fall (approx) ft
		ft/sec	mph	
Mouse	19	38	26	22
Rat	180	44	30	30
Guinea pig	650	31	21	15
Rabbit	2,600	31	21	15
Man (computed)	72,574 (160 lbs)	26	18	11

*Data from Richmond et al. [34]

TABLE 9

APPROXIMATE IMPACT VELOCITIES AND EQUIVALENT HEIGHTS OF DROP FOR FRACTURE OF HUMAN SPINE, SKULL, FEET, AND ANKLES*

Effects on Man	Impact Velocity		Equivalent Height of Drop in.	Comment
	ft/sec	mph		
Experimental Skull Fracure	13.5-22.9	9.5-15.0	37-91	Range of 1 to 99 per cent fracture of cadaver heads dropped on flat metal surface.
Fracture of feet and ankles	12-13	8-9	25-30	Impact-table data using cadavers with knees locked.
Fracture of lumbar spine	8	6	12	Estimated for impact on hard surface in sitting position.

*Data from Gurdjian et al., [31] Draeger et al., [35] and computed from Ruff. [36]

reached 40 to 78 ft/sec did 16 of 50 goats (33 per cent) suffer death or fractures. It was concluded in that reference that 50 per cent of the personnel exposed to velocities in the 40-to-78-ft range would sustain fractures, paralysis, or death from rolling over flat, grassy ground.

Range-Yield-Effects Relationships for Tertiary Blast Damage

Table 10 summarizes the criteria, based on the above data, for tertiary blast effects estimated for man.[2,21-25] The impact velocities associated with a given biological effect pertain to random, whole body impacts against a hard, flat surface. It has been assumed that 10 ft/sec would, in most instances, be of no consequence. The threshold, 50-per cent and near 100-per cent lethality, would be associated with impacts of 20, 26 and 30 ft/sec. Included in the table are the impact velocities related to various incidences of skull fractures.

Figure 19 contains the range-yield-effect relationships for tertiary blast injury connected with whole body impact involving a hard sur-face.[2,23-25] These curves specifically apply to man's average presented area (acceleration, coefficient equal to 0.03 sq ft/lb*); in other words, man tumbling or rotating in flight. Further, the curves apply to ideal or near-ideal wave forms and to the free-field condition or to a geometry in which 10 ft of travel is possible before impact.

COMPARISON OF RANGE-YIELD-EFFECT RELATIONSHIPS FOR BLAST EFFECTS WITH THERMAL AND IONIZING RADIATION

A comparative range-yield diagram appears in Figure 20. It compares the ranges at which primary, secondary, and tertiary blast effects extend with those for first- and second-degree burns and for initial ionization radiation doses of 100 and 200 rem. The latter were scaled from data given in reference 26. As noted in the figure, the range for each effect grows with explosive yield. Because the range increase with yield is the least for nuclear radiation, the greatest for thermal, and in between for blast over-pressure, the free-field hazards are relatively different for any range in the detonation of explosives having low, intermediate, and high yields. In other words, for a few kilotons or less, the initial nuclear radiation places an area at hazard which is relatively great compared to blast and thermal effects. On the other hand, for hundreds of kilotons and many megatons, thermal and all the blast effects (primary, secondary, and tertiary) encom-pass areas of risk that far surpass those for initial nuclear radiation.

The slope of the impact-velocity curve is comparable to that of second-degree burns and is exceeded only by the rate of rise of the first-degree-burn curve. Consequently, for high-yield explosions, the potential for impact

---

*Acceleration coefficient = presented area multiplied by the drag coefficient divided by the mass.

TABLE 10

TENTATIVE CRITERIA FOR TERTIARY BLAST EFFECTS

Critical organ or event	Related impact velocity ft/sec*
Total body[+]	
Mostly "safe"	10
Lethality threshold	20
Lethality 50 per cent	26
Lethality near 100 per cent	30
Skull fracture[+]	
Mostly "safe"	10
Threshold	13
50 per cent	18
Near 100 per cent	23

*Applies to uncontrolled impact with hard, flat surface.
[+]Data from Richmond et al., [34] Gurdjian et al., [31] and Swearingen et al. [38]

RANGE-YIELD RELATIONSHIP for INDICATED TERTIARY BLAST DAMAGE to 165-lb AVERAGE MAN* for SEA-LEVEL SURFACE BURSTS

Applies to ideal or near-ideal wave forms

Impact injury+: absent or minimal
Impact injury+: lethality, threshold
Impact injury+: lethality, near 100 percent

10 ft/sec*
20*
30*

Computed for 165-lb "average" man; acceleration coefficient = .03 sq ft/lb
* when translated distance = 10 ft
+ for total body impact

Yield

Range, mi

Figure 19

-40-
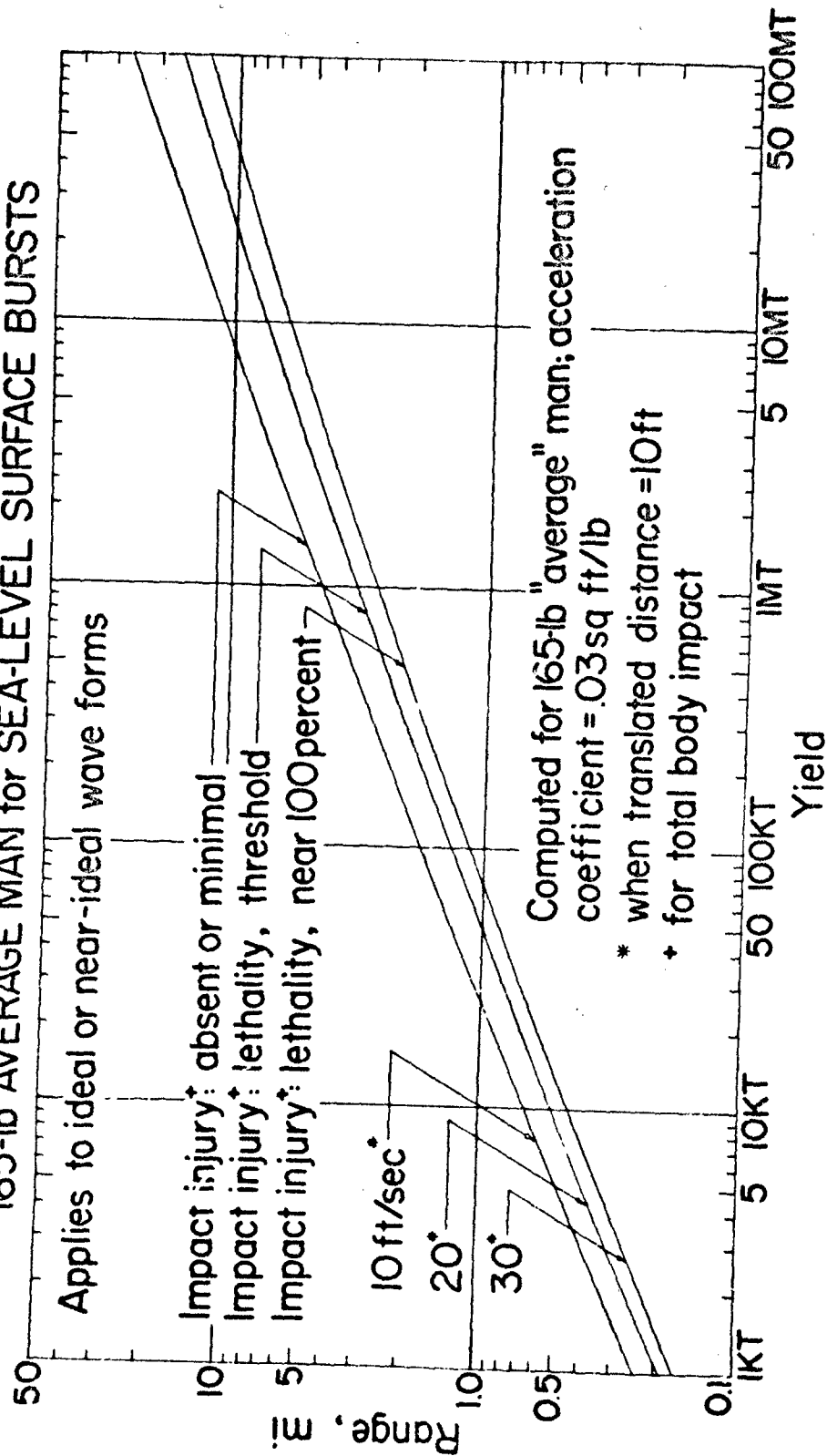
COMPARATIVE-EFFECTS DATA SHOWING RANGES INSIDE WHICH INDICATED BIOLOGICAL RESPONSES MAY OCCUR for SEA-LEVEL SURFACE BURSTS

Applied to Ideal or Near-ideal Wave Forms
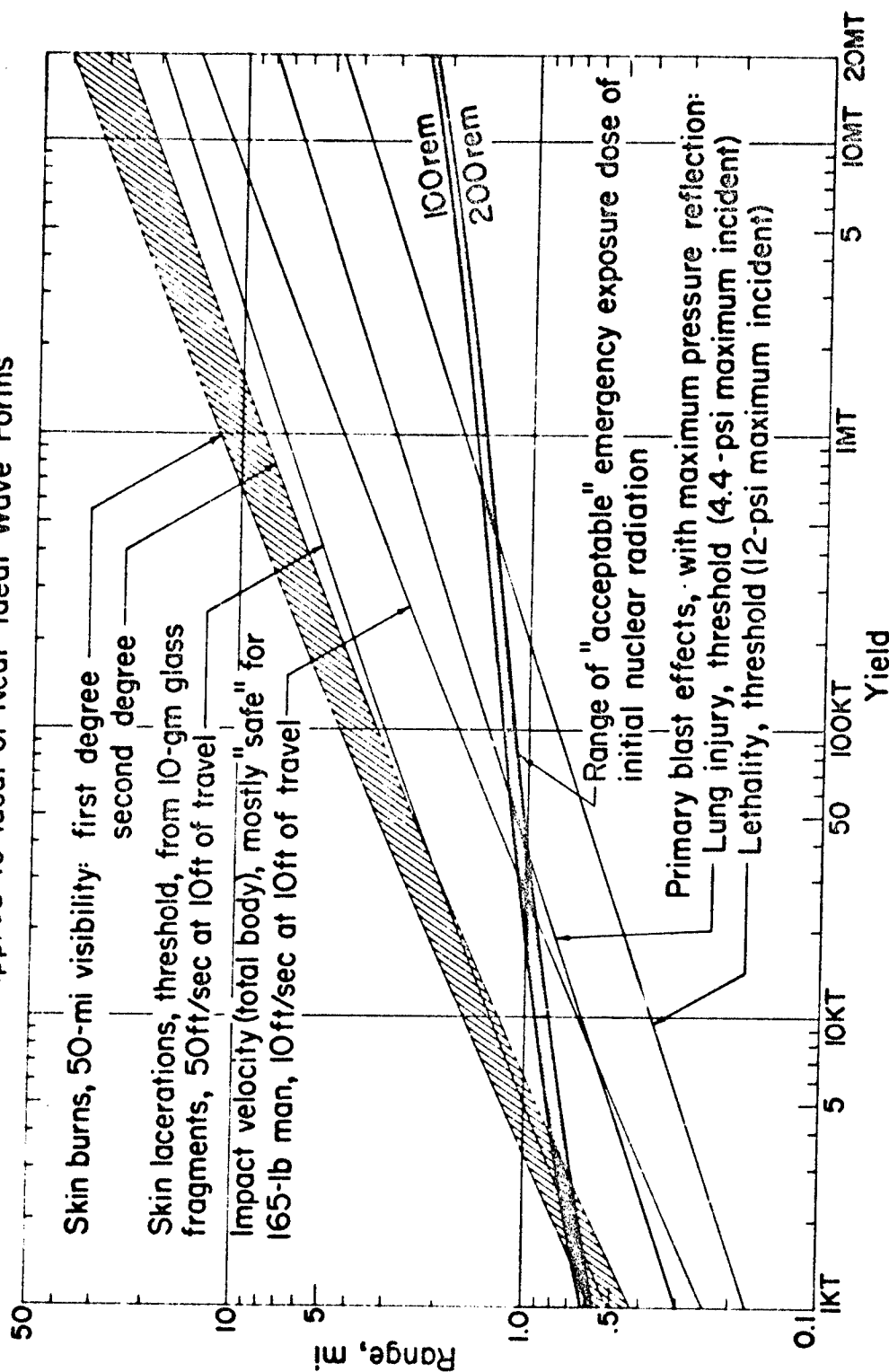
Figure 20

injury associated with displacement becomes a matter of great concern over large areas about ground zero.

Finally, it should be pointed out that, as far as they go, the particular tentative biological end-points chosen appear fairly sound, but no doubt will require refinement and extension in the years ahead as more information becomes available. Although the range-yield-effects relationships are rather crude, they do, in a general way, specify the range (and area) of risk and allow one to define the range inside which protection would be helpful for any target-range situation. These curves serve as a valuable guide to planning experimental and theoretical studies aimed at both their improvement and the compilation of similar range-yield-effects curves dealing with the combined effects of blast and thermal and nuclear radiation on personnel.

REFERENCES

1. White, C. S., T. L. Chiffelle, D. R. Richmond, W. H. Lockyear, I. G. Bowen, V. C. Goldizen, H. W. Merideth, D. E. Kilgore, B. B. Longwell, J. T. Parker, F. Sherping and M. E. Cribb, "The Biological Effects of Pressure Phenomena Occurring Inside Protective Shelters Following Nuclear Detonation," USAEC Civil Effects Test Group Report, WT-1179, Office of Technical Services, Department of Commerce, Washington, D. C., October 28, 1957.

2. White, C. S., I. G. Bowen and D. R. Richmond, "Biological Tolerance to Air Blast and Related Biomedical Criteria," to be published in the proceedings of the Protective Construction Symposium held in Washington, D. C. on April 20, 1965. Published as USAEC Civil Effects Test Operations Report, CEX-65.4, Office of Technical Services, Department of Commerce, Washington, D. C., October 18, 1965.

3. Vortman, L. J., H. Birnbaum, E. Laing, F. G. Ort, R. V. Schumacher and C. C. Hudson, "The Effects of an Atomic Explosion on Group and Family Type Shelters," USAEC Civil Effects Test Group Report, WT-1161, AEC Technical Information Service Extension, Oak Ridge, Tenn., January 21, 1957.

4. Richmond, D. R., V. R. Clare, V. C. Goldizen, D. E. Pratt, R. T. Sanchez and C. S. White, "Biological Effects of Overpressure. II. A Shock Tube Utilized to Produce Sharp-Rising Overpressures of 400 Milliseconds Duration and Its Employment in Biomedical Experiments," Technical Progress Report No. DASA 1246, Defense Atomic Support Agency, Department of Defense, Washington, D. C., April 7, 1961. Also in Aerospace Med., 32: 997-1008, 1961.

5. Richmond, D. R., V. C. Goldizen, V. R. Clare and C. S. White, "The Overpressure-Duration Relationship and Lethality in Small Animals," Technical Progress Report No. DASA 1325, Defense Atomic Support Agency, Department of Defense, Washington, D. C., September 10, 1962.

6. Clare, V. R., D. R. Richmond, V. C. Goldizen, C. C. Fischer, D. E. Pratt, C. S. Gaylord and C. S. White, "The Effects of Shock Tube Generated Step-Rising Overpressures on Guinea Pigs Located in Shallow Chambers Oriented Side-On and End-On to the Incident Shock," Technical Progress Report No. DASA 1312, Defense Atomic Support Agency, Department of Defense, Washington, D. C., May 31, 1962.

7. Schardin, H. and O. Wünsche, "Versuche an Kleintieren zur Bestimmung der Druckstosstödlichkeitsgrenze," Bericht V 17, Deutsche Versuchsanstalt für Luftfahrt e. V., January 1958.

8. Richmond, D. R., V. R. Clare and C. S. White, "The Tolerance of Guinea Pigs to Air Blast when Mounted in Shallow, Deep, and Deep-with-Offset Chambers on a Shock Tube," Technical Progress Report No. DASA 1334, Defense Atomic Support Agency, Department of Defense, Washington, D. C., October 27, 1962.

9. Richmond, D. R., M. B. Wetherbe, R. V. Taborelli, T. L. Chiffelle and C. S. White, "The Biologic Response to Overpressure. I. Effects on Dogs of Five to Ten-Second Duration Overpressures Having Various Times of Pressure Rise," J. Aviat. Med., 28: 447-460, 1957.

10. Benzinger, T., "Physiological Effects of Blast in Air and Water," Chap. XIV-B, German Aviation Medicine, World War II, Vol. II, pp. 1225-1259, U. S. Government Printing Office, Washington, D. C., 1950.

11. Richmond, D. R. and C. S. White, "A Tentative Estimation of Man's Tolerance to Overpressures from Air Blast," in Proceedings of the Symposium on Effectiveness Analysis Techniques for Non-Nuclear Warheads against Surface Targets, October 30-31, 1962, Vol. I, pp. L to L-34, U. S. Naval Weapons Laboratory, Dahlgren, Virginia, Technical Progress Report No. DASA 1335, Defense Atomic Support Agency, Department of Defense, Washington, D. C., November 7, 1962.

12. Froboese, M. and O. Wünsche, "Todlichkeitsgrenzen für Albino-Ratten bei Luftstossbelastung in Abhängigkeit von der Strossrichtung und Druckverlafsform," Rapport Bericht, Band I: Text, 2/59, French-German Research Institute of Saint-Louis, France, June 30, 1959.

13. Richmond, D. R., D. E. Pratt and C. S. White, "Orbital 'Blow-Out' Fractures in Dogs Produced by Air Blast," Technical Progress Report No. DASA 1316, Defense Atomic Support Agency, Department of Defense, Washington, D. C., April 10, 1962.

14. Richmond, D. R., R. V. Taborelli, F. Sherping, M. B. Wetherbe, R. T. Sanchez, V. C. Goldizen and C. S. White, "Shock Tube Studies of the Effects of Sharp-Rising, Long-Duration Overpressures on Biological Systems," USAEC Technical Report, TID-6056, Office of Technical Services, Department of Commerce, Washington, D. C., March 10, 1959.

15. Richmond, D. R., DASA Project, Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico, unpublished data.

16. Anderson, R. S., F. W. Stemler and E. B. Rogers, "Air Blast Studies with Animals II," U. S. Army Chemical Research and Development Laboratories, Technical Report, CRDLR 3049, DASA 1193, Army Chemical Center, Md., April 1961.

17. Schardin, H. and O. Wünsche, personal communication.

18. Lee, R. H., F. I. Whitten and F. W. Brown III, "The Decompression Component of Air Blast," Medical Research Report No. 4, Research Report Project NM 64 01 23 BUMED, U. S. Navy Mine Defense Laboratory, Panama City, Fla., June 1959.

19. Zalewski, Teofil, "Experimentelle Untersuchungen über die Resistenzfähigkeit des Trommelfelle," Z. Ohrenheilkund, 52: 109-128, 1906.

20. Richmond, D. R., R. V. Taborelli, I. G. Bowen, T. L. Chiffelle, F. G. Hirsch, B. B. Longwell, J. G. Riley, C. S. White, F. Sherping, V. C. Goldizen, J. D. Ward, M. B. Wetherbe, V. R. Clare, M. L. Kuhn and R. T. Sanchez, "Blast Biology — A Study of the Primary and Tertiary Effects of Blast in Open Underground Protective Shelters," USAEC Civil Effects Test Group Report, WT-1467, Office of Technical Services, Department of Commerce, Washington, D. C., June 30, 1959.

21. White, C. S., "Biological Effects of Blast," presented before The Armed Forces Medical Symposium, Field Command, Defense Atomic Support Agency, Sandia Base, Albuquerque, New Mexico, November 28, 1961. Technical Progress Report No. DASA 1271, Defense Atomic Support Agency, Department of Defense, Washington, D. C., December 1961.

22. White, C. S., I. G. Bowen, D. R. Richmond and R. L. Corsbie, "Comparative Nuclear Effects of Biomedical Interest," USAEC Civil Effects Test Operations Report, CEX-58.8, Office of Technical Services, Department of Commerce, Washington, D. C., January 12, 1961.

23. White, C. S., I. G. Bowen and D. R. Richmond, "A Comparative Analysis of Some of the Immediate Environmental Effects at Hiroshima and Nagasaki," presented before the Eighth Annual Meeting of the Health Physics Society, New York City, on June 11, 1963. USAEC Civil Effects Test Operations Report, CEX-63.7, Office of Technical Services, Department of Commerce, Washington, D. C., August 1964. Also in Health Physics, 10: 89-150, 1964.

24. White, C. S., "Tentative Biological Criteria for Assessing Potential Hazards from Nuclear Explosions," Technical Progress Report No. DASA 1462, Defense Atomic Support Agency, Department of Defense, Washington, D. C., December 1963.

25. White, C. S., I. G. Bowen and D. R. Richmond, "The Environmental Medical Aspects of Nuclear Blast," presented before the National Preparedness Symposium sponsored by The National Institute for Disaster Mobilization, Inc., Washington, D. C., on November 13, 1962, Technical Progress Report No. DASA 1341, Defense Atomic Support Agency, Department of Defense, Washington, D. C., November 1962.

26. Glasstone, S., Editor, The Effects of Nuclear Weapons, Revised Edition, Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., April 1962.

27. Bowen, I. G., A. F. Strehler and M. B. Wetherbe, "Distribution and Density of Missiles from Nuclear Explosions," USAEC Civil Effects Test Group Report, WT-1168, Office of Technical Services, Department of Commerce, Washington, D. C., December 14, 1956.

28. Bowen, I. G., D. R. Richmond, M. B. Wetherbe and C. S. White, "Biological Effects of Blast from Bombs. Glass Fragments as Penetrating Missiles and Some of the Biological Implications of Glass Fragmented by Atomic Explosions," USAEC Report, AECU-3350, Office of Technical Services, Department of Commerce, Washington, D. C., June 18, 1956.

29. Bowen, I. G., Mary E. Franklin, E. R. Fletcher and R. W. Albright, "Secondary Missiles Generated by Nuclear-Produced Blast Waves," USAEC Civil Effects Test Group Report, WT-1468, Office of Technical Services, Department of Commerce, Washington, D. C., October 28, 1963.

30. USAEC Project, Lovelace Foundation for Medical Education and Research, Albuquerque, N. M., unpublished data.

31. Gurdjian, E. S., J. E. Webster and H. L. Lissner, "Studies on Skull Fracture with Particular Reference to Engineering Factors," Amer. J. Surg., 78: 736-742, 1949.

32. Bowen, I. G., R. W. Albright, E. R. Fletcher and C. S. White, "A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves," USAEC Civil Effects Test Operations Report, CEX-58.9, Office of Technical Services, Department of Commerce, Washington, D. C., June 29, 1961.

33. Taborelli, R. V., I. G. Bowen and E. R. Fletcher, "Tertiary Effects of Blast — Displacement," USAEC Civil Effects Test Group Report, WT-1469, Office of Technical Services, Department of Commerce, Washington, D. C., May 22, 1959.

34. Richmond, D. R., I. G. Bowen and C. S. White, "Tertiary Blast Effects: Effects of Impact on Mice, Rats, Guinea Pigs and Rabbits," Technical Progress Report No. DASA 1245, Defense Atomic Support Agency, Department of Defense, Washington, D. C., February 28, 1961. Also in Aerospace Med., 32: 789-805, 1961.

35. Draeger, R. H., J. S. Barr, J. Y. Dunbar, W. W. Sager and M. C. Shelesnyak, "A Study of Personnel Injury by 'Solid Blast' and the Design and Evaluation of Protective Devices," Naval Medical Research Institute Report No. 1, Project X-517, Bethesda, Md., March 30, 1945.

36. Ruff, S., "Brief Acceleration: Less Than One Second," Chap. VI-C, German Aviation Medicine, World War II, Vol. I, pp. 584-597, U. S. Government Printing Office, Washington. D. C., 1950.

37. De Haven, Hugh, "Mechanics of Injury Under Force Conditions," Mech. Engr., 66: 264-268, 1944.

38. Swearingen, J. J., E. B. McFadden, J. D. Garner and J. G. Blethrow, "Human Tolerance to Vertical Impact," Aerospace Med., 31: 989-998, 1960.

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Lovelace Foundation for Medical Education & Research, Albuquerque, New Mexico	UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

Biological Effects of Blast and Shock

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Progress

5. AUTHOR(S) *(Last name, first name, initial)*

Richmond, Donald R.
White, Clayton S.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1966	61	38

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
DA-49-146-XZ-055	
b. PROJECT NO.	DASA 1777
03.012	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. AVAILABILITY/LIMITATION NOTICES

Distribution of This Report is Unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	DASA

13. ABSTRACT

The scope of blast and shock biology was set forth as covering effects resulting from overpressure (primary), flying debris (secondary), and displacement (tertiary). Procedures employed in the laboratory for simulating the blast wave forms as they varied within structures on nuclear tests were described.

For each effect, a selected summary of current information relating the physical parameters to given levels of biological response was presented. From this, the blast and shock hazards estimated for personnel, as a function of range and yield, were illustrated in the form of curves.

The range-yield-effects relationship for the biological criteria was discussed in terms of free-field and other exposure situations. They were compared with similar range-effects data for thermal and nuclear radiation.

DD FORM 1473 `1 JAN 64`

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Blast						
Shock						
Biological Effects						
Overpressure						
Missiles						
Displacement						
Biological Criteria						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (corporate author) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (either by the originator or by the sponsor), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

END